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DYNAMICAL ASPECTS OF PHOTOSYNTHESIS[1]

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Although a great amount of attention has been paid to photosynthesis, nothing is known of the dynamics of the process. This aspect of the matter especially deserves investigation as furnishing a new point of attack upon this difficult problem.

We cannot analyze the dynamics of photosynthesis without first securing accurate data. A preliminary difficulty lies in the control of temperature. When leaves of land plants are exposed to sunlight, changes of temperature at once take place in the leaf and it is found that even under favorable conditions of control the temperature of the leaf may fluctuate as much as 10°C. in a half hour period.

To avoid this difficulty, the writers have employed certain aquatic plants, consisting of thin layers or filaments, whose temperature can be regulated to a sufficient extent for the purposes of the investigation.

The fronds of the marine alga, *Ulva rigida* (sea lettuce), are so suitable for this purpose that most of the experimental work was confined to them, although other material was used for comparison. These fronds consist of only two layers of cells and are so thin (about 0.078 mm.) that their temperature remains very close to that of the surrounding liquid. A further advantage of thin fronds is that gaseous exchange is extremely rapid.

To obtain data for the study of dynamics, it is necessary to determine at frequent intervals how much photosynthesis has taken place. This was accomplished by a method elsewhere described.[2] This method enables us to measure quickly and accurately the amount of photosynthesis at definite intervals, without subjecting the plants to an abnormally high concentration of CO_2 as has heretofore been customary.[3] It depends upon the fact that photosynthesis abstracts carbonic acid from the surrounding solution and renders it more alkaline. By the use of indicators the degree of alkalinity, and

consequently the amount of photosynthesis, can be determined with considerable precision.

The amount of photosynthesis is approximately a linear function of the change in PH value in the range here employed.

In order to measure the degree of alkalinity produced by *Ulva* under the influence of sunlight, a piece of the frond was placed in a tube of Pyrex glass filled with sea water and closed as described elsewhere.[2] The tube was then placed in a large water bath (the temperature of which fluctuated less than 1°C.) in direct sunlight. If clouds interfered with the sunlight at any time the experiment was rejected.

Since the plants produce CO_2 by respiration this must be taken into consideration. Experiments were conducted under precisely the same conditions, except that light was excluded. They agree in showing that the respiration was practically constant. It cannot, therefore, affect the form of the curve of photosynthesis.

TABLE 1

PERIOD	NUMBER OF MINUTES REQUIRED TO PRODUCE STANDARD ALKALINITY	TOTAL NUMBER OF MINUTES EXPOSED	AMOUNT OF PHOTOSYNTHESIS	
			Observed	Calculated
1st	35.7	35.7	1	0.92
2nd	25.9	61.6	2	2.07
3rd	23.3	84.9	3	3.18
4th	21.7	106.6	4	4.23
5th	20.4	127.0	5	5.23
6th	20.3	147.3	6	6.22
7th	20.5	167.8	7	7.22

Average of 5 experiments at 27°±0.5°C.

In each experiment the procedure was the same. Freshly collected *Ulva* (young, dark green fronds not more than 3 or 4 inches long) was placed over night in running sea water and covered so that in the morning no light could reach it. In starting an experiment the *Ulva* was placed in a closed tube in sea water containing a trace of alcoholic phenolphthalein and exposed to light until a definite shade of pink was produced.[4] This shade of pink matched that of a standard buffer solution (whose PH value was determined by the gas chain) containing the same concentration of indicator as the sea water (and observed in a Pyrex tube of the same size).

When the standard shade was attained, the time of exposure was noted. The sea water was then poured out of the tube containing *Ulva* (the last drop being removed by shaking), fresh sea water was added, and a new determination was made of the time required to attain the standard shade.

The results obtained are given in table 1 (average of five experiments). The table shows that the time required to reach the standard shade steadily diminishes until a constant value is reached.

This result is surprising, but it has been confirmed by numerous experiments on *Ulva*, as well as by experiments on *Enteromorpha*, *Spirogyra*, *Hydrodictyon*, *Potamogeton*, and other plants.[5]

It is therefore evident that photosynthesis is a process which shows a gradual acceleration until a steady rate is attained.[6] A question of great interest now presents itself: What is the cause of the initial acceleration and why is a steady rate attained after a certain length of time?

The suggestion which first offers itself is that photosynthesis belongs to the class of autocatalytic processes, in which the reaction is catalyzed by one of its own products. Such reactions begin slowly but as more of the catalyzing substance is produced the reaction goes on at an increasinlgy rapid rate until it begins to slow down as the reacting substances are used up. If these substances are constantly renewed, the reaction will not slow down but continue to go on more and more rapidly.

In our experiments on photosynthesis the reacting substances are constantly renewed.[7] The substances entering into the reaction are presumably carbon dioxide and water. The concentration of the water remains constant, while as soon as the concentration of the carbon dioxide has diminished by a very small amount it is brought back to the original point by the renewal of the sea water.

If photosynthesis were an autocatalytic reaction, it should, under these conditions, continue to increase in speed as time goes on. As a matter of fact it soon attains a steady rate. This might be accounted for by supposing that the concentration of the catalyst cannot exceed a certain amount, being limited by its own solubility. But in that case the rate would increase more and more rapidly up to a certain point and suddenly become stationary when the limit of solubility was reached.[8] This is not the case. The rate increases rapidly at first then more and more slowly until it finally becomes stationary.

It might be supposed that the speed of the reaction is checked by the accumulation of the products of the reaction. In that case, however, the rate would not become constant but would gradually diminish to zero. Such influence of the products would be possible only in the case of a reversible reaction and we have no ground for believing that photosynthesis comes under this head.[9]

It might also be suggested that the rate becomes constant through the operation of a 'limiting factor' such as lack of light, carbon dioxide, or of temperature. But it is evident that the effect of such a factor would be fully felt at the very start of the reaction and that it could not cause a gradual falling off in the increase of speed.

This puts clearly before us a fundamental difficulty. The fact that the rate increases most rapidly at first and then more slowly shows that photosynthesis is not an autocatalytic reaction in the usual sense of the word, for in such a reaction[10] the rate would increase slowly at first, then more and more

rapidly as time goes on. We must therefore conclude that photosynthesis belongs in a different category.

The key to the situation is furnished by the figures in the second column of table 1 which show that if the reaction is catalyzed by a substance, it must be produced more rapidly at first and then more and more slowly. It is also evident that this substance must be limited in amount and that when its production ceases the rate of photosynthesis stops increasing and becomes constant. We may assume that the rate of photosynthesis is proportional to the amount of the catalyst, which we will call C. The figures suggest that this substance may be produced in the manner characteristic of a monomolecular reaction. We may therefore assume that C is produced by a substance A, under the influence of sunlight, according to the monomolecular reaction: $A \rightarrow C$.

We may now proceed to test this assumption by calculating the amount of photosynthesis which is to be expected after the lapse of a given time.

According to the ordinary equation for a monomolecular reaction,

$$C = A - Ae^{-KT}$$

in which T is time, e is the basis of natural logarithms, and K is the velocity constant of the reaction.

If the rate of photosynthesis is directly proportional to the amount of C, we may, for convenience, put

$$\text{Rate of photosynthesis} = \frac{dP}{dT} = C;$$

hence

$$\frac{dP}{dT} = A - Ae^{-KT}.$$

On integration this becomes

$$\frac{P}{A} = T - \frac{1}{K} + \frac{1}{K}e^{-KT}.$$

When the rate has become constant we find that a unit amount of photosynthesis is produced in 20.4 minutes (average of the last 3 periods in table 1), hence the rate of photosyntheses at that time is $1 \div 20.4 = 0.049$. This is by assumption equal to C when A is completely transformed into C and this is in turn equal to A at the beginning of the reaction. Hence A at the start $= 0.049$. We may substitute this value in the equation and find the value of K by trial. If we put $K = 0.049$ we get the values given in table 1. Better agreement with the observed values is obtained by taking lower values of K. This produces a gradual falling off in subsequent values, but it is possible that this might actually occur if the experiment could be continued for a sufficient length of time.

The agreement between the observed and the calculated values is very satisfactory except at the start. In this connection it may be pointed out that at the beginning of a reaction disturbances are to be expected.

It is therefore evident that the assumption justifies itself by giving an adequate quantitative explanation of the observed results. The question then arises whether it is a natural one. It would seem very probable that the light produces a substance which accelerates the reaction and unless this substance is produced in unlimited amount there must come a time when the rate will become steady (or fall off). The assumption therefore seems to be reasonable.

It is attractive to form a hypothesis as to the nature of the catalyst. One might be tempted to suppose that it is chlorophyll but for the fact that some plants which are deep green may not photosynthesize as rapidly as those which possess less chlorophyll.[11] It is of course possible that the less active plants are deficient in some essential factor other than chlorophyll. On the other hand it may be necessary for chlorophyll to be transformed by the light from an inactive into an active form,[12] so that the rate of photosynthesis depends on the amount of 'active chlorophyll' present. This would be analogous to the well known activation of enzymes by various means.

An equally satisfactory quantitative explanation is obtained if we suppose the amount of photosynthesis to correspond to the amount of a substance P, produced (under the influence of light) by the reaction

$$S \rightarrow M \rightarrow P,$$

in which S represents a constant source, (i.e., a substance which does not appreciably diminish during the experiment).

We may suppose that in the morning, before the frond is exposed to the light, S alone is present. On exposure to light the formation of M and P occurs. The amount of M will then increase until it reaches a constant value (when its rate of formation is equal to its rate of decomposition) but the value of P will continually increase, since it does not undergo decomposition. When M has reached a constant value we find (putting K as the velocity constant of the reaction $M \rightarrow P$) that the amount of M decomposed in 1 minute (unit time) is KM; this is also the amount of P which is formed in 1 minute and since the reaction $S \rightarrow M$ produces just enough of M to balance the loss of M (by transformation into P) the amount of M produced each minute is KM. Hence if we start in the morning with S alone there will be produced each minute KM and all of this will be transformed into P except what is present at any moment as M. Hence the amount of P produced in the time T is $KMT - M$.

We may, for convenience, put $M = 1$ when it has attained its constant value; the rate of increase of P is then constant and we find that it takes 20.4 minutes to produce 1 unit of photosynthesis. Hence $KMT = 1$. Substi-

tuting in this equation the values of M and T we have $20.4\ K = 1$ whence $K = 0.049$.

At the start of the reaction the value of M is 0: this gradually increases to 1 and remains constant. During this period of increase the value of M may be calculated as follows: When M has reached its constant value ($M = 1$) let us suppose that the reaction $S \rightarrow M$ suddenly stops while $M \rightarrow P$ continues; we shall find that if T minutes have elapsed after this occurrence, the amount of M which has disappeared is $1 - e^{-KT}$. If the reaction $S \rightarrow M$ had not stopped it would have produced enough of M so that (in spite of the fact that M is constantly decomposing) the amount of M remaining at the time T would be just enough to balance the loss, or $1 - e^{-KT}$. Hence if we start with nothing but S (the values of M and of P being zero) the amount of M present after the lapse of any given time T will be $1 - e^{-KT}$ and the amount of P will be

$$P = KT - (1 - e^{-KT})$$

This becomes the same as the equation

$$\frac{P}{A} = T - \frac{1}{K} + \frac{1}{K} e^{-KT},$$

when in the latter we put $K = A$ as was done in making the calculations given in table 1. Hence when we substitute the value $K = 0.049$ in the equation $P = KT - (1 - e^{-KT})$ we obtain the values already given in table 1.

If the chlorophyll takes part in the reaction by decomposing or by combining (as some recent evidence indicates), we might suppose that S represents inactive chlorophyll, M active chlorophyll and P a derived substance which combines with CO_2. At present it does not seem profitable to attempt a more extended discussion of this question. But it may be pointed out that (as one of us has recently emphasized)[13] consecutive reactions of the type here discussed, are to be looked upon as the rule, rather than as the exception, in living matter.

It is evident that either of the theories developed above gives a quantitative explanation of the results. Both seem to be based on reasonable assumptions. Future investigation must decide which is more useful.

In any event, it is clear that much is to be learned concerning the dynamics of photosynthesis, and it is hoped that the considerations here set forth may be of value in this connection.

Summary.—Ulva which has been kept in the dark begins photosynthesis as soon as it is exposed to sunlight. The rate of photosynthesis steadily increases until a constant speed is attained.

This may be explained by assuming that sunlight decomposes a substance whose products catalyze photosynthesis or enter directly into the reaction.

Quantitative theories are developed to account for the facts.

[1] Preliminary communication.

[2] The paper will appear shortly in *Science, New York*, N. S., 1918. All the precautions mentioned in this account were carefully observed in the present investigation.

[3] The methods previously used in studying the photosynthesis of aquatic plants are not as accurate as the one here described, nor do previous experiments afford the kind of data needed for our purpose. Cf. Blackman, F. F., and Smith, A. M., *Proc. Roy. Soc., London*, (B) **83**, 1911, (389).

[4] All matching of shades was done under a 'Daylight' lamp, so that uniform conditions were assured throughout the experiments. Cf. *Science, New York*, N. S., **42**, 1915, (764). A clear space was left in the tube below the *Ulva* to facilitate comparison of colors. In any single experiment the buffer may be dispensed with by using as a standard the pink solution produced by the first exposure. The first exposure should be as short as is consistent with obtaining a definite standard. Experiments showed that the trace of alcoholic phenolphthalein had no injurious effect.

[5] In experiments on fresh water algae a small amount of sodium bicarbonate was added to the water.

[6] This acceleration is not due to the increase in the intensity of light as the sun gets higher for it was also observed when the experiments were started at noon.

[7] When the sea water is not changed during the experiment the curve rises more rapidly at first then bends over to the right as the supply of CO_2 is used up.

[8] This is because the catalyst from the moment of its production is in solution. It is not analogous to a solid going into solution, which dissolves more slowly as the limit of solubility is approached.

[9] While respiration is in a sense the opposite of photosynthesis the steps in the process are apparently quite different from those found in photosynthesis.

[10] I. e., under the conditions of the present experiment, where the reacting substances are kept approximately constant in composition.

[11] Aquatic plants taken directly from ice-covered ponds in winter are found to possess but feeble photosynthetic power, though of a deep green color.

[12] The activation of substances by light is well known in photochemistry.

[13] *J. Biol. Chem., New York*, **21**, 1917, (585); **22**, 1917, (23).

MOBILITIES OF IONS IN AIR, HYDROGEN, AND NITROGEN

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In spite of the great number of investigations devoted to gases the question whether an ion is a molecule or an atom carrying an elementary charge, or whether it is a number of neutral molecules clustering about a charge is not as yet definitely settled. Both the 'cluster' hypothesis, according to which an ion is conceived of as a unit elementary charge surrounded by a satellite of neutral molecules, and the 'small-ion' hypothesis, according to which an ion is conceived of as a single molecule carrying an elementary charge, explain equally well the phenomenon which first necessitated the former, and also the older, hypothesis; this phenomenon being the fact that the mobilities and the diffusion coefficients of the ions in gases are relatively

small in comparison with those of the uncharged molecules in the same gases. They also explain equally well a certain number of other phenomena, but experiments designed to test directly the validity of one or the other of these hypotheses led to contradictory results.

The measurement of the mobilities of ions under various pressures and different electric field-strengths has always been generally conceded as the mode of attack in the solution of the problem. For if the older, the cluster, hypothesis is true the cluster would break up when the ion acquired a sufficiently high kinetic energy and the mobility would increase abnormally. But if the small-ion theory is true there would be no such dissociation and the mobility would remain normal. Quite a number of such measurements have been made, and they gave contradictory results. For instance, Latty,[1] Kovarick,[2] Todd,[3] Townsend,[4] Franck,[5] Moore,[6] Haines,[7] and Ratner[8] found the mobility to increase abnormally, whereas Chattock,[9] Wellisch,[10,11] and Loeb[12] found it normal over a wide range of potentials applied. In view of these results further experiments seemed desirable and hence the work herein described was undertaken.

The method here employed was the Rutherford[13]-Franck[14] method as employed by Loeb.[12] The apparatus was fully described in Loeb's articles.

Results: a. Air.—An attempt first to repeat Loeb's work with air gave the following results:

TABLE 1

TABLE OF RESULTS OBTAINED FOR IONIC MOBILITIES IN AIR, FEBRUARY–MARCH, 1917

$U+$	$U-$	$X+$	$X-$	P	$K+$	$K-$	R
1. 60 cycles, 119 volts							
1.12	1.75	168	134	746	1.10	1.72	1.56
1.12	1.75	168	134	746	1.10	1.72	1.56
1.12	1.75	168	134	752	1.10	1.73	1.56
1.25	1.73	168	134	742	1.22	1.70	1.38
Mean					1.14	1.72	1.51
2. 14,758 cycles, 5000 volts							
1.64	1.98	14,160	12,870	752	1.62	1.92	1.21
1.57	1.84	14,160	12,870	750	1.56	1.82	1.17
1.64	1.98	14,160	12,870	749	1.61	1.95	1.21
1.57	1.84	14,160	12,870	746	1.55	1.81	1.17
1.82	2.10	13,810	12,650	692	1.66	1.92	1.17
2.26	2.61	12,300	11,550	558	1.66	1.91	1.16
Mean					1.61	1.90	1.18
Mean of both sets					1.37	1.81	1.34

$U+$ = Mobility of positive ions. $U-$ = Mobility of negative ions. X = Field strength in volt/cm. P = Pressure in mm. $R = K- /K$. K = Mobility at 760 mm. pres. $X- /P$ Max. = 20.70, Min. = 0.18. $X+ /P$ Max. = 22.04, Min. = 0.22.

It may be seen from the above table that the mean values of R, the ratio of the negative to the positive mobilities, are different for the two frequencies employed, and it appears as though the mobilities did vary—since the ratio could not vary unless either or both of the mobilities did. But the following considerations will show that this difference is ascribable to experimental variations. In the first place, the results of different experimenters, and even those of the same experimenter, show a maximum variation of almost 30%, for instance, from $R = 1.16$ to 1.37 (Wellisch), or from $R = 1.15$ to 1.93 (Loeb). Both of these authors attribute the variations to external variations of their experiments. Thus a slight external variation of some kind is liable to cause such a variation in the ratio without the mobilities themselves being varied at all. Furthermore, if the mobilities tend at all to vary with field-strength, their variations would be much greater than are manifested since the field-strength is 168 volt/cm. in one case and 14,160 volt/cm.

TABLE 2

RESULTS OBTAINED FROM THE MEASUREMENTS ON HYDROGEN, MAY-JUNE, 1917

$U+$	$U-$	$X+$	$X-$	P	$K+$	$K-$	R
14,758 cycles, 4000 volts							
5.51	8.20	6669	5668	748	5.43	8.10	1.49
5.92	8.20	6669	5668	748	5.81	8.10	1.38
5.51	8.20	6669	5668	746	5.40	8.10	1.49
8.20	12.21	5668	4723	518	5.58	8.35	1.49
14.94	20.99	4192	3524	290	5.70	8.15	1.41
14.94	20.99	4192	3524	300	5.84	8.35	1.41
Mean.....					5.56	8.19	1.45

in the other. Or, it may be said that even if the ratio does vary about 20% when the field-strength is increased from 169 to 14,160 volt/cm. (about 8333%), it may be considered constant for all practical purposes. However, there were enough of the experimental uncertainties to account for the variation.

Thus the conclusion is that between the field-strength of 168 and 14,160 volt/cm. the mobility of the positive ions remains absolutely normal, and the mobility of the negative ions remains normal also between 134 and 12,870 volt/cm.

These results more than amply substantiate those obtained by Loeb and it is therefore quite safe to conclude that the evidences obtained so far point decidedly in the direction of the small-ion theory.

b. Hydrogen. The results of the measurements in hydrogen with the high frequency high potential field are shown in table 2.

It may be seen from the table that with a potential gradient of 6669 volt/cm. or $X/p = 14.45$, the positive mobility remains normal. The nega-

tive mobility also remains absolutely normal with 5668 volt/cm. or X/p = 12.15. Thus it may be concluded that the law Up = constant, where U = mobility and p = pressure in mm. mercury, is verified for hydrogen up to these limits.

Besides the normal positive and negative ions the existence of free negative electrons in hydrogen was proved. These electrons existed in abundance when the gas was freshly prepared and disappeared entirely after the gas had remained in the ionization chamber for about six or eight hours. The disappearance of the electrons might conceivably be the result either of their fast dissipation into the walls of the chamber or of their ready formation of negative ions with the neutral molecules of either hydrogen or the impurities from the sealing wax that had evaporated into the chamber in the meantime.

TABLE 3

$U+$	$U-$	$X+$	$X-$	P	$K+$	$K-$	R
			60 cycles				
5.28		77.8		748	5.21		
5.50	8.80	25.0	16.5	746	5.41	8.65	1.52
6.60	11.19	20.0	13.0	600	5.22	8.80	1.62
8.95	13.28	29.5	24.0	498	5.85	8.70	1.48
13.90	22.00	19.8	11.5	300	5.49	8.69	1.58
22.91	31.06	16.5	99.0	198	5.95	8.15	1.34
	9.26		28.0	746		9.26	
Mean					5.52	8.71	1.57

$X-/P$ Max. = 12.15, Min. = 0.38. $X+/P$ Max. = 14.45, Min. = 0.66.

An effort was made to search for the two other kinds of negative ions which Haines claimed to have found.[7] And as no trace of these other ions could be found it was thought that the disposition of the apparatus employed might not have been sufficiently adequate for their detection. Consequently it was considered desirable to repeat Haines' experiment in order to rectify the present method. Thus Haines' experimental conditions were reproduced as exactly as possible according to his descriptions with the expectation of obtaining similar results.

The results of this operation are shown in table 3.

These results agree with those obtained in the employment of the high frequency high potential field in showing that no such intermediate negative ions existed. This, together with a careful study of Haines' curves, led to the conclusion that in so far as experimental results are concerned there is not a scrap of evidence, either in Haines' results or in those obtained in the present experiment, of these other species of negative ions which were claimed to exist by Haines.

It may be proper to mention here that no sooner had the above conclusion been arrived at than it received corroboration from Wellisch's latest paper[18] in which it was reported that no trace could be found of Haines' ions *B* and *C*.

Incidentally an interesting fact was revealed in the comparison between the two sets of curves. If was found that the amount of free negative electrons present in the gas was smaller when under high than when under low potential. This would seem to suggest that the electrons—or some of them at least—did actually attach themselves to neutral molecules when a high potential was applied and thus formed negative ions. This would not be at all

TABLE 4

RESULTS OBTAINED FOR NITROGEN, JULY, 1917

$U+$	$U-$	$X+$	$X-$	P	$K+$	$K-$	R
			1. 60 cycles				
17.60	22.96	15.0	11.5	60	1.39	1.81	1.30
	10.15		26.0	140		1.87	
2.81	3.88	47.0	33.5	360	1.33	1.84	1.38
1.27	1.65	51.0	40.0	750	1.26	1.63	1.30
1.36	1.84	50.0	38.0	745	1.33	1.80	1.35
1.34	1.82	49.8	38.0	745	1.31	1.78	1.36
Mean.....					1.32	1.79	1.34
			2. 14,758 cycles, 5000 volts				
1.31	1.84	17,670	14,880	750	1.29	1.82	1.40
1.31	1.84	17,670	14,880	745	1.28	1.80	1.40
1.31	1.84	17,670	14,880	742	1.28	1.80	1.40
2.76	3.93	13,910	10,110	360	1.31	1.86	1.42
2.76	3.93	13,910	10,110	345	1.26	1.78	1.42
Mean.....					1.28	1.81	1.41
Mean of both frequencies					1.30	1.80	1.38

$X-/P$ Max. = 29.0, Min. = 0.05. $X+/P$ Max. = 40.0, Min. = 0.07.

impossible since the tremendous velocity imparted to them by the high field would enable them to produce ions from neutral molecules by attaching themselves to the latter. It would be interesting to find out where, that is, at what potential—other conditions remaining the same—this sort of ionization actually would begin.

c. Nitrogen.—Table 4 shows the results of the mobility measurements in nitrogen. The maximum potential gradient employed was 17,670 volt/cm. for the positive and 14,880 volt/cm. for the negative ions. The mobilities remained absolutely normal up to these limits and the law Up = constant was found to be applicable here as it was in the case of air and hydrogen.

Here too an abundance of free negative electrons was found, although the amount was not so great as that found in hydrogen under the same pressure.

Conclusion and Discussion.—As the results of the present experiment exhibit no deviation from the law Up = constant it follows that both the positive and the negative ions did not disintegrate at the potentials employed. It may be seen from the tables that the values of X/p were very close to the values at which sparking would occur in the respective gases. And since the cluster hypothesis demands the disintegration of the ions when the values of X/p are much lower than those employed,[15] it therefore follows that these results are directly contradictory to this hypothesis.

On the other hand, the results are in perfect accord with the small-ion hypothesis. Taking this in conjunction with the results of other experiments, especially those of Wellisch and Loeb, there does not seem any question at all regarding the validity of this hypothesis.

There remains, however, an experimental fact which the cluster hypothesis seems to be able to explain better than the small-ion hypothesis, and that is the difference between the mobilities of the positive and the negative ions. For, if both the positive and the negative ions are single molecules carrying elementary charges different only in signs, why should they have different mobilities? Whereas if the ions are clusters the difference in their mobilities may be ascribed to the difference between the numbers of molecules constituting the two kinds of ions.

This difficulty of the small-ion theory, however, is more apparent than real in view of the recent theories as to the electronic constitution of matter. If an atom consists of a positive nucleus surrounded by a satellite of negative electrons held together by the attractive force from the nucleus, the phenomenon of ordinary molecular collision must be attributed to the repulsion between the two systems of negative electrons in the colliding molecules[16,17]. Since, according to the small-ion theory, the only difference between the uncharged molecules and the ions lies in the number of negative electrons in the satellites—the negative ion having one more electron, and the positive ion one less than the uncharged molecules—it follows that the only difference between the ordinary molecular collisions and the collisions between ions and uncharged molecules is that between the numbers of electrons in the colliding systems. It is only reasonable, therefore, to extend the conception of the ordinary molecular collision to cover the case of collision between ions and uncharged molecules. Now since the negative ion has more of these peripheral negative electrons than the positive ion it follows that the repulsion between the negative ion and the uncharged molecule is greater than that between the positive ion and the uncharged molecule; and the attractive force between the negative ion and the uncharged molecule is smaller than that between the positive ion and the uncharged molecule. This results in a difference in the *effective mean free paths* of the two kinds of ions. The positive ion, by virtue of the greater attractive force existing between it and the uncharged

molecules, drags the latter more towards it and thus has a smaller *effective mean free path*. The negative ion, with the smaller attractive force, has a greater *effective mean free path*. As the mobility varies directly with the mean free path, it can be easily seen why the negative ions have a greater mobility than the positive ions.

But the above explanation would not be applicable to the case where the ratio of the negative to the positive mobility is less than unity, for that would mean that the attractive force between the negative and the uncharged molecule is greater than that between the positive ion and the uncharged molecule, which would be impossible according to the theory upon which the explanation is based. Fortunately, in such cases the differences between the positive and the negative mobilities are so small that they are well within the limits of experimental fluctuations; consequently, until it is conclusively established that there are cases where the positive mobilities are greater than the negative by a quantity much too great to be accounted for by experimental conditions, the above explanation seems to be the most reasonable one so far advanced.

The detailed paper has been communicated to the *Physical Review*.

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THERMO-ELECTRIC ACTION WITH DUAL CONDUCTION OF ELECTRICITY

By Edwin H. Hall

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Communicated February 16, 1918

In a paper[1] presented before the National Academy of Sciences in November, 1917, I discussed thermo-electric action in metals on the hypothesis of progressive motion by the 'free' electrons only. I have now extended the discussion to the case of dual electric conduction; that is, conduction maintained in part by the free electrons (electrons F) and in part by the associated electrons (electrons A), the latter passing directly from atomic union to atomic union.

I do this because, though we may not at present have a satisfactory theory[2] of electric conduction involving such action of the associated electrons, we are equally far from having a satisfactory theory of conduction as a function of the free electrons only.

I take it as self-evident that, whereas electric potential-gradient acts upon both free and associated electrons, tending to carry them in the direction of decreasing negative potential, free-electron pressure-gradient acts on the free electrons only. The necessary result of this consideration is the conclusion that, if electrons (A) as well as electrons (F) can move progressively through a metal, we shall, in a detached bar of metal having a temperature gradient from one end to the other, have a constant procession of free electrons from the place of high electron-gas pressure, the hot end of the bar, toward the place of low pressure, the cold end, while an equal procession of associated electrons moves in the opposite direction. For the mechanical tendency of the free electrons toward the cold end maintains an excess of negative potential at this end, with a corresponding deficiency at the hot end; and the electric potential-gradient thus established drives associated electrons from cold to hot, while it opposes, without being able entirely to prevent, the movement of free electrons from hot to cold.

The state of mobile electrical equilibrium thus presented to our imagination involves no violation of commonly accepted principles. The slight, extremely slight, reduction of electron mechanical pressure below the normal equilibrium pressure at the hot end of the bar induces there continual passage of the electrons from the associated to the free state, evaporation, let us say, with absorption of heat. At the cold end, on the other hand, the very slight excess of electrical mechanical pressure, above the normal value proper to the temperature, induces continual passage of electrons from the free to the associated state, condensation, let us say, with release of heat. The whole operation carries heat from the hot to the cold end of the bar, and it is, in fact,

somewhat analogous to the action of a steam heating-system, the free-electron movement corresponding to the stream of steam and the associated electrons movement to the return flow of the water.

My conception of the action, for a case in which there is no lateral loss or gain of heat, is set forth diagrammatically in figure 1, in which the dotted lines indicate movement of the free electrons and the full lines movement of the associated electrons.[3]

In my previous paper,[1] dealing with the hypothesis of progressive motion of 'free' electrons only, I rejected as unnecessary the assumption of a specific attraction of metals for electrons. But with the more complicated conditions dealt with in the present paper we cannot avoid this assumption; for without it we should have thermal conduction without initial difference of temperature, and so a violation of the second law of thermodynamics, in a bar of alloy varying in composition from metal α at one end to metal β at the other. There must be no progressive movement of free electrons from one end to the other, or of associated electrons in the opposite direction, in such a bar. The superior mechanical pressure of the free electrons at the α end will produce a slight initial movement establishing a potential gradient along

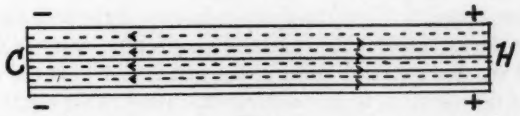

FIG. 1

the bar, the α end becoming positive and the β end negative; but the influence of this potential gradient on the associated electrons must be offset by a specific atomic attraction directed toward the β end. It is reasonable to suppose that the smaller free-electron density at the β end is due to the superior attraction of the β positive nucleus compared with the α nucleus. The resulting equilibrium, the inhibition of circulation of the electrons from one end to the other of the bar and back, is analogous to the equilibrium in a system made up of water, water-vapor, and a solution-column sustained by osmotic pressure. The upper end of such a column, with its reduced vapor-pressure, corresponds to the β end of our bar with its small free-electron pressure. The force of gravitation, directed from the top to the bottom of the column, is analogous to the electrical potential gradient from the β end toward the α end of the bar.

Naturally the question arises whether a bar of one metal having a temperature gradient, and a free electron density rising with the temperature, has not a differential specific attraction tending to move electrons toward the cold end. There may be such an attraction, and it will be well for us to take account of it, but where there is a temperature-gradient we are not

obliged to suppose a dead-lock between the potential gradient and this differential specific attraction. The conception of electron circulation, with thermal conduction (or convection), in a detached unequally heated bar survives the admission of specific attraction; but the whole matter now becomes more involved.

In addition to the potential, P, due to electric charge, we must now think of a potential, P_a, due to the differential attraction of the unequally heated, unhomogeneous, metal for the associated electrons, and also of a potential, P_f, due to the differential attraction of the metal for the free electrons. Both classes of molecules are subject to the charge-potential P, but electrons (A) only are subject to the potential P_a, and electrons (F) only are subject to the potential P_f.

Under hypothesis (A): If we assume, as hypothesis (A), that the mechanical tendency of the free electrons, if acting without electric forces, would produce equality of pressure from end to end of the bar, the condition of equilibrium (see fig. 1) in a detached bar hot at one and cold at the other is

$$\mu\left[\left(\frac{dl}{dl}.dl + \frac{d(P+P_b)}{dl}.nedl\right) \div nmdl\right]ne = -k_a\frac{d(P+P_a)}{dl} \qquad (1)$$

where (dp/dl) is the gradient of mechanical pressure of the free electrons along the bar of length l, n is the number-density of the free electrons in the metal, m is the mass and e the charge of an electron, μ is the coefficient of mobility of the free electrons through the metal, and k_a is the electric conductivity of the metal, so far as conductivity is due to the electrons (A).

A simple formula,

$$\mu = k_f.\frac{1}{Gme^2}, \qquad (2)$$

where G is $(1/m)$, connects μ with the free-electron specific conductivity, k_f. Evidently

$$G = nv, \qquad (3)$$

where v is the volume of one gram of free electrons in the metal.

Very simple operations, using equations (2) and (3), derive from (1) the form

$$(P_c - P_h) + \int_h^c \frac{k_f}{k_a+k_f}.dP_f + \int_h^c \frac{k_a}{k_a+k_f}.dP_a = \frac{1}{Ge}\int_c^h \frac{k_f}{k_a+k_f}.vdp, \quad (4)$$

in which the integration extends from the hot end (h) to the cold end (c) of the bar.

The first member of this equation is the amount of reversible work that would be done by or on the unit quantity of electricity in passing *through* the bar, if it were made part of a closed thermo-electric circuit. This is something different from, probably smaller than, $(P_c - P_h)$, which is the *charge* poten-

tial-difference between the two ends of the bar. The quantity expressed by the whole first member I shall call the *virtual* e.m.f., resident in the bar because of its temperature gradient.

The form of the second member shows that the virtual e.m.f. can be represented by an area on the *P-V* plane. Thus, if the line *A D* in figure 2 represents the pressure-volume relations of the free electrons for the whole length of the bar, so that

$$area\ EADG = \int_c^h vdp,$$

we shall have

$$area\ EA'D'G = \int_c^h \frac{k_f}{k_a + k_f} . vdp,$$

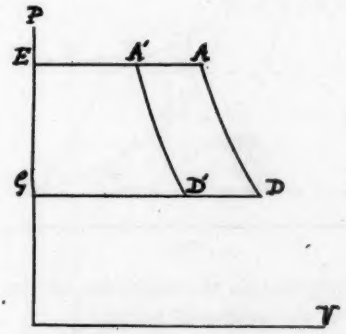

FIG. 2

provided we make the width of this area correspond at every height to the value of $k_f/(k_a + k_f)$ for that height.

Without the conception of dual conductivity and specific attraction we should, as my previous paper[1] shows, have in place of (4) the simple equation

$$P_c - P_h = \frac{1}{Ge}\int_c^h vdp.$$

with dual conductivity but without specific attraction we should have

$$P_c - P_h = \frac{1}{Ge}\int_c^h \frac{k_f}{k_a + k_f} . vdp.$$

Obviously, then, the participation of the electrons (A) in the conductivity reduces the e.m.f. due to the temperature gradient in the bar. In fact, the part which associated electrons play in thermo-electric action is analogous to that played by entrained water in the work done by steam. The larger the

proportion of water, the smaller is the mechanical effect per unit mass of the mixture.

In the isothermal alloy 'bridge,' of composition varying from pure α at one end to pure β at the other end, which is supposed to connect the two metals at their hot or at their cold ends, we must have, when it stands detached, no cyclic movement of the electrons. Accordingly we get, in place of equation (1), the two equations

$$dP + dP_a = 0 \tag{5}$$

and

$$dP + dP_f = -\frac{dp}{ne} = -\frac{1}{Ge}.vdp. \tag{6}$$

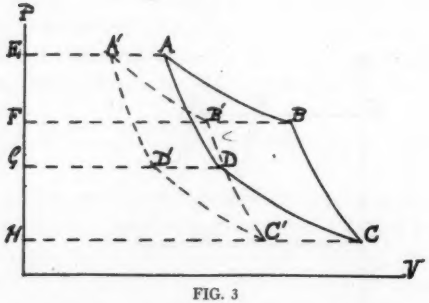

FIG. 3

These lead to the following, as the expression for the *virtual* e.m.f. due to the non-homogeneity of the isothermal bridge:

$$\int_{\alpha}^{\beta} \frac{k_f}{k_a + k_f}(dP + dP_f) = \frac{1}{Ge}\int_{\beta}^{\alpha} \frac{k_f}{k_a + k_f}.vdp. \tag{7}$$

The first member of (7) is the reversible work that would be done, on the free electrons only, during the passage of the unit quantity of electricity through the bridge.

The expression for the work done on the electrons (A) is absent here, for the reason that, according to equation (5), no *reversible* work would be done on them.

For a thermo-electric circuit, made up of a bar of metal α, a bar of metal β, and two isothermal alloy bridges α–β, we find the net, or total, virtual e.m.f. to be represented by $(1 \div Ge)$ times the area $A'\ B'\ C'\ D'$ in figure 3, where $A\ B$, $B\ C$, $A\ D$, and $D\ C$ indicate the pressure-volume relations of one gram of free electrons in the four parts of the circuit respectively, and $A'\ B'$, $B'\ C'$, $A'\ D'$, $D'\ C'$, are found respectively from the corresponding full lines by means of the ratio $k_f \div (k_a + k_f)$, applied as in figure 2.

In spite of the conspicuous part which the specific potentials P_a and P_f

play in the local virtual e.m.fs. of the circuit, we can, by making a gap in any isothermal homogeneous part of this circuit and inserting there an electrometer, measure the total e.m.f. as a simple difference of charge-potential. The total, or net, amount of work done by or against the specific attractions which enter into P_a and P_f is zero for any quantity of electricity which goes completely through the circuit.

Under hypothesis (B): If, in place of hypothesis (A), we assume that the mechanical tendency of the free electrons is towards the condition of equilibrium which holds for thermal effusion, each local virtual e.m.f. will be represented by an area like $E'\ A'\ D'\ G'\ g'e'$ in figure 4, where E' is the mid-point of $E\ A'$ and G' is the mid-point of $G\ D'$. But the combination of four such areas, one for each of the lines $A'\ B'$, $B'\ C'$, $A'\ D'$, and $D'\ C'$, of figure 3, will give precisely the same net result that is represented in figure 3 by

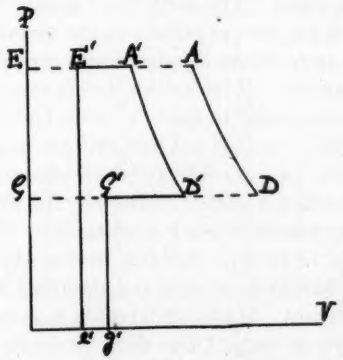

FIG. 4

$A'\ B'\ C'\ D'$. The total e.m.f. is, then, precisely the same under hypothesis (B) as under hypothesis (A). This is because the fundamental conditions of p and v, represented by the lines $A\ B$, $B\ C$, $C\ D$, and $D\ A$, in figure 3, remain substantially the same under hypothesis (B) as under hypothesis (A).

[1] These PROCEEDINGS, **4**, 1918, (29–35).

[2] For suggestions see a paper by myself in these PROCEEDINGS, March, 1917, and one by P. W. Bridgman in the *Physical Review*, April, 1917, p. 269.

[3] I am not without hope that the mechanism here suggested will prove to be of great service in the theory of heat conduction. It seems probable that the free electrons within a metal are quite incapable, acting as a permanent gas, of accounting for the magnitude of the metal's heat conductivity. But it is a familiar fact that the heat-carrying power of a vapor, involving evaporation and condensation, is vastly greater than that of a permanent gas. It appears, from the imperfect data now at my command, that the operation illustrated by figure 1 would give thermal conductivity of the right order of magnitude.

This conception of thermal conductivity, a conception occurring quite incidentally and unexpectedly, has already been communicated to the American Physical Society in a paper read at the meeting of December, 1917.

TERRESTRIAL TEMPERATURE AND ATMOSPHERIC ABSORPTION

By C. G. Abbot

Astrophysical Observatory, Smithsonian Institution

Read before the Academy, November 21, 1917

The earth's temperature depends mainly on the balance of incoming solar energy and outgoing terrestrial energy of radiation. These two classes of rays lie chiefly in two far-separated regions of spectrum. Of solar rays, 98% lie between 0.3 and 3.0 microns (μ) of wave-length. Of terrestrial rays about the same proportion lie between 5 and 50 microns. According to Abbot and Fowle's researches, about 40% of the solar rays directed towards the earth are reflected to space. The earth must radiate to space $1.93 \times 0.60 \times 0.25$, or 0.29 calorie per cm^2 per minute on the average from its whole surface to keep a steady temperature in balance with the solar rays received over the area of its cross section. If the earth's surface was a perfect radiator and its radiation passed unhindered to space, it would emit according to Stefan's law $8 \times 10^{-11} \times (287)^4 = 0.55$ cal. per cm^2 per minute. How shall we explain the discrepancy between 0.29 and 0.55 calories?

1. Is the earth's surface a perfect radiator? Its surface is about three-fourths water. Of the remainder much is moist soil or moist vegetation. The radiative power of the earth must therefore be near that of water. My colleague, Mr. Aldrich, has lately studied the absorbing and reflecting powers of water for long-wave rays. He finds that of the rays emitted by lamp-black paint at 100°C. a layer of water 1 cm. thick transmits none and reflects as follows:

Incidence	0°	30°	55°	63°	70°	72°
Reflection	2%	3%	7%	10%	17%	22%

As the absorption is 1− (Refl. + Trans.) he computes that of rays reaching a water surface from a hollow hemispherical enclosing lamp-black-painted surface at 100°, the absorption would be 90%. Experiments on lamp-black paint having shown nothing strongly selective about its radiation in this region of spectrum, we seem justified in concluding, in accord with Kirchoff's law, that water is a 90% perfect radiator in this region of spectrum. As is water, so is the earth's surface. Hence we conclude that the earth's surface sends out 0.50 calorie per cm^2 per minute on the average.

2. How much of this does the atmosphere transmit? My colleague Mr. Fowle has recently published[1] results of a long investigation of this subject in which he studied the spectrum up to a wave-length of 17μ by aid of a spectro-bolometer with rock salt prism. He employed a very long tube in which the beam traversed paths of air up to 250 meters in length containing quanti-

ties of water vapor up to the equivalent of 0.3 cm. of precipitable water. He also observed the solar spectrum to 17μ through paths of atmosphere containing water vapor up to the equivalent of 3.0 cm. of precipitable water. Since rock salt ceases to be sufficiently transparent beyond 17μ Fowle's spectrum work stopped there. But Aldrich, on Mount Wilson, by experiments not yet entirely finished, seems to have shown that neither incoming sun-rays nor outgoing earth-rays non-transmissible to rock-salt (that is over 17μ in wave-length) can traverse the atmosphere. Assuming that this result will be confirmed we have the following results from Fowle's and Aldrich's investigations representing the output and atmospheric transmission of rays from a perfect radiator at earth temperature.

Per cent of atmospheric transmission for stated cm. ppt. H_2O

WAVE-LENGTH	INTENSITY	CM. 0.003	CM. 0.03	CM. 0.3	CM. 3.0
μ μ					
4– 5	50	15	45	70	95
5– 6	142	16	43	66	95
6– 7	242	45	85	95	100
7– 8	315	13	42	85	100
8– 9	360	0	2	40	50
9–10	380	0	0	0	15
10–11	370	0	2	5	40
11–12	350	0	0	4	10
12–13	320	0	0	13	20
13–16	810	100	100	100	100
16–20	510	90	100	100	100
> 20	1,450	100	100	100	100
4–∞	5,300	49	57	66	75

From these results Fowle has computed that in clear weather, when precipitable water in the atmosphere is 1 cm., the atmosphere transmits 28% to space of the radiation emitted by the earth's surface. In the tropics where a load of atmospheric humidity equal to precipitable water of 3 cm. or more is common, the transmission would not exceed 20% on clear days. A. Angström has shown[2] that on cloudy nights practically all radiation from the earth's surface to space is cut off. Hence (as it is cloudy half the time on the average of the earth's surface) out of 0.50 calories per square centimeter per minute emitted, the average escape to space, taking both clear weather and cloudy, is only 0.06 calories. As 0.29 calories per cm^2 per minute on the average must leave the planet earth, and as the earth's surface contributes, only 0.06 calories, it follows that the atmosphere is the main radiating source, furnishing three-fourths of the output of radiation of the earth as a planet.

Principal sources of the atmospheric radiation in order of their importance are: (1) The clouds; (2) water-vapor; (3) ozone; (4) carbon-dioxide. Ther e

is little difference between the importance of the ozone band at 10 μ and the carbon-dioxide band at 15 μ except that the former falls at a point in the spectrum where terrestrial radiation is most intense, and where water-vapor has almost no absorption, while the latter falls at a place where the radiation is not so intense and where water-vapor also absorbs powerfully.

No ozone band was found by Fowle in his work with the long tube, but in the solar spectrum it shows strongly. This accords with work of others who show that ozone is found only at high atmospheric levels. Apparently there is not enough ozone in the atmosphere to produce complete absorption in its band at 10 μ, and it may be that the earth's temperature would be profoundly altered if the ozone contents of the air could be changed. If it were possible, for instance, to charge the surface air above citrus fruit orchards strongly with ozone on a frosty night, perhaps hurtful frosts could thereby be warded off.

Carbon-dioxide exists in the atmosphere so plentifully that its full possible influence seems probably to be exerted. No increase of CO_2 would seem likely to produce a considerable effect on terrestrial temperature, and it is probable that the CO_2 content of the air could be reduced to less than a quarter of its present amount without notable temperature effects.

[1] *Smithsonian Misc. Coll., Washington*, **68**, No. 8.
[2] *Ibid.*, **65**, No. 3, p. 54.

MOBILITIES OF IONS IN VAPORS

By Kia-Lok Yen

Ryerson Physical Laboratory, University of Chicago

Communicated by R. A. Millikan, January 21, 1918

In a former paper on the Mobilities of Ions in Air, Hydrogen, and Nitrogen (these Proceedings, **4**, 1918, 91), the conclusion was reached that the so-called cluster hypothesis could no longer claim any reason for its existence and that the arguments for the small-ion theory should be considered conclusive.

It only remained for the small-ion theory to offer an adequate explanation for the difference between the positive and negative mobilities exhibited by all experimental results. This difference can easily be explained by the cluster hypothesis for if the ions were constituted by satellites of molecules surrounding single charges, the difference between the positive and negative mobilities could be ascribed to the difference between the number of constituent molecules in a positive and that in a negative ion. But with the small-ion theory such an explanation is not possible, since all ions are conceived of as single charged molecules.

In the aforementioned paper, an explanation for this experimental fact

was offered on the basis of the Rutherford nucleus-atom theory. It was shown there that the difference between the two mobilities is due to the difference between the numbers of negative electrons in the two kinds of ions. There exists a greater attractive force between the positive ions and the uncharged molecules than that between the negative ions and the uncharged molecules on account of the fact that negative ions have more electrons than the positive. This results in a smaller mean free path, and hence a smaller mobility, for the positive ions than for the negative.

From this point of view it is evident that an excess of positive over negative mobility is scarcely to be expected in either gases or vapors. Since there has been very little work done on vapors and since some careful measurements of mobilities in them are necessary for the verification of this explanation in particular and of the small-ion theory in general, it was considered desirable to make some careful determinations in vapors, and hence the following work was undertaken.

Method and Procedure.—The method and procedure here employed were the same as those employed in the previous experiment. The only difference between this experiment and the former is that in the present one only low frequency alternating field was employed. This was because the vapors worked with required that pressures be sufficiently low for them to remain in the vaporized state, and at such pressures the high frequency high potential oscillating field proved inapplicable on account of the sparking across the gauze and the collecting plate. However, this difference does not at all effect the results, as the main purpose of employing the high potential field was to find out whether the mobilities would increase abnormally, and—since it had already been proved that they did not—the employment of the high potential field in the present experiment was entirely unnecessary.

Another difference between the present and the previous experiment is that in this one a different ionization chamber was used. This chamber was constructed on precisely the same plan as the former, but covered with a bell jar of about one-sixth the size of that covering the former apparatus. This last arrangement is more convenient in that it allowed the contents of the chamber to be evacuated and refilled with ease, and that the vapors were rendered as free of impurities as possible.

The vapors were produced by the same method as that employed by Wellisch.[1]

The measurements were made in the same manner as before, and the results calculated from the same formula.

Results.—The following tables show the results obtained for the various vapors used. It may be seen from these tables that the results for all these vapors at the various pressures are perfectly consistent with the law that the pressure times the mobility is constant, and that the mean values for the positive mobilities are—excepting in the case of C_2H_5I—smaller than those for the negative mobilities. In the case of C_2H_5I the mean

values may be considered the same. Therefore, the results of the present experiment are directly opposed to those obtained by Wellisch in 1909[1] in so far as the ratios of the negative to the positive mobilities are concerned.

In table 10 there is comparison between the results obtained by Wellisch and those obtained by me. It may be of interest to note that in 1912[2] Wellisch himself reversed his results for C_2H_6O, C_5H_{12}, and SO_2.

TABLE 1

SULPHUR DIOXIDE (SO_2)

P	$U+$	$U-$	$K+$	$K-$	R
60	5.327	5.547	0.421	0.437	1.04
70	4.523	4.523	0.416	0.416	1.00
80	4.935	4.035	0.423	0.423	1.00
90	3.329	3.371	0.394	0.399	1.01
105	2.833	2.895	0.398	0.407	1.02
120	2.669	2.561	0.421	0.404	0.96
Mean.....			0.412	0.414	1.00

TABLE 2

ETHYL ALCOHOL (C_2H_6O)

P	$U+$	$U-$	$K+$	$K-$	R
15	19.728	19.024	0.389	0.378	0.97
20	14.017	14.017	0.369	0.369	1.00
25	11.097	11.097	0.365	0.365	1.00
30	9.513	9.864	0.375	0.388	1.03
40	6.053	7.008	0.319	0.367	1.15
Mean.....			0.363	0.373	1.03

P = pressure in mm. mercury. $U+$ = Positive mobility. $U-$ = Negative mobility. $K+$ = Positive mobility reduced to 760 mm. mercury. $K-$ = Negative mobility reduced to 760 mm. mercury. $R = K-/K+$.

TABLE 3

ALDEHYDE (C_2H_4O)

P	$U+$	$U-$	$K+$	$K-$	R
30	7.885	8.560	0.311	0.338	1.09
34		7.885		0.352	
38	5.993		0.300		
43	5.256	5.548	0.297	0.313	1.07
45	5.166	5.350	0.306	0.317	1.05
50	4.832	5.078	0.318	0.334	1.05
55	4.280	4.610	0.310	0.333	1.07
Mean.....			0.307	0.331	1.07

TABLE 4

PENTANE (C_5H_{12})

P	$U+$	$U-$	$K+$	$K-$	R
30	8.812	12.483	0.347	0.493	1.42
40	7.491	8.812	0.394	0.462	1.18
50	5.993	6.968	0.397	0.445	1.12
50	5.993	6.968	0.397	0.445	1.12
60	4.832	5.448	0.382	0.430	1.12
66	4.540	4.994	0.394	0.434	1.10
Mean.....			0.385	0.451	1.17

TABLE 5

ETHYL CHLORIDE (C_2H_5Cl)

P	$U+$	$U-$	$K+$	$K-$	R
30	7.683	7.885	0.303	0.311	1.02
40	5.762	5.993	0.303	0.317	1.05
40	5.549	5.762	0.292	0.303	1.04
50	4.756	5.078	0.313	0.334	1.07
50	4.681	4.833	0.308	0.318	1.03
Mean.....			0.304	0.317	1.04

TABLE 6

ACETONE (C_3H_6O)

P	$U+$	$U-$	$K+$	$K-$	R
50	3.699	4.035	0.243	0.265	1.09
60	2.959	3.131	0.235	0.247	1.05
64	2.833	2.959	0.239	0.250	1.07
70	2.513	2.665	0.229	0.245	1.07
76	2.336	2.421	0.234	0.242	1.03
80	2.219	2.296	0.234	0.242	1.03
Mean.....			0.236	0.247	1.04

TABLE 7
ETHYL ACETATE ($C_4H_8O_2$)

P	U+	U−	K+	K−	R
50	3.309	3.648	0.219	0.240	1.09
60	2.567	3.167	0.229	0.250	1.09
65	2.701	2.900	0.231	0.248	1.07
70	2.421	2.663	0.223	0.245	1.09
75	2.290	2.533	0.226	0.250	1.10
80	2.172	2.334	0.230	0.246	1.07
Mean.....			0.226	0.247	1.09

TABLE 8
ETHYL IODIDE (C_2H_5I)

P	U+	U−	K+	K−	R
30	5.166	4.833	0.203	0.191	0.94
35	4.104	4.161	0.189	0.192	1.01
50	2.466	2.512	0.162	0.169	1.04
60	2.336	2.296	0.184	0.181	0.98
60	2.141	2.166	0.169	0.171	1.01
Mean.....			0.181	0.181	1.00

TABLE 9
METHYL IODIDE (CH_3I)

P	U+	U−	K+	K−	R
50	3.222	3.390	0.212	0.223	1.05
60	2.607	2.926	0.219	0.231	1.06
65	2.572	2.959	0.220	0.236	1.07
70	2.296	2.421	0.212	0.223	1.05
75	2.230	2.270	0.220	0.224	1.02
80	2.043	2.090	0.215	0.220	1.02
Mean			0.216	0.226	1.05

TABLE 10
COMPARISON

VAPOR	WELLISCH				K.-L. YEN	
	1909[1]		1915[2]		1917	
	K+	K−	K+	K−	K+	K−
C_2H_4O	0.31	0.30			0.307	0.331
C_2H_6O	0.34	0.27	0.39	0.412	0.363	0.373
C_3H_6O	0.31	0.29			0.236	0.247
SO_2	0.44	0.41	0.415	0.414	0.412	0.414
C_2H_5Cl	0.33	0.31			0.304	0.317
C_6H_{12}	0.36	0.35	0.370	0.440	0.385	0.451
$C_4H_8O_2$	0.31	0.28			0.226	0.247
C_2H_5I	0.17	0.16			0.181	0.181
CH_3I	0.21	0.22	0.24	0.233	0.216	0.226

Conclusion.—From the results of the present experiment, it is evident that the apparent difficulty with the explanation proposed for the difference between the positive and negative mobilities does not really exist at all. It only remains for the exponents of the small-ion theory to deduce an exact formula for the mobility of ions on the basis of the Rutherford-Bohr theory from which we should expect that the peripheral negative electrons in the molecules and the ions would play the dominant if not indeed the only rôle in collisions.

I wish it to go on record that the present experiment was undertaken at the suggestion of Prof, R. A. Millikan, and under his direction; and also to thank Mr. W. R. Westhafer for his assistance in taking some of the measurements and computing some of the results.

[1] *Phil. Trans. R. Soc., London,* (A), **209,** 1909, (249).
[2] *Phil. Mag., London,* **34,** 1917, (59).

A CONTRIBUTION TO THE PETROGRAPHY OF THE SOUTH SEA ISLANDS

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A brief statement of the geological structure and general character of the rocks of the Islands of Tahiti, Moorea, and the Society Group has been given in a previous number of the Proceedings of the National Academy, from which it appears that each island is a profoundly eroded volcano, consisting mainly of basaltic lavas rich in olivine and augite, with inconspicuous feldspar, and that at five of the volcanic islands there are trachytic or phonolitic lavas which have been erupted late in the period of activity. In two volcanoes erosion has exposed coarsely crystallized cores of gabbroic and theralitic rocks with peridotites, and in one case syenites and nephelite-syenites as the latest eruptions.

Nearly seventy years ago J. D. Dana called attention to these syenitic rocks on Tahiti, and remarked that they were only a feldspathic variety of the same igneous rocks that constitute the island. Eight years ago Lacroix published a description of the alkalic rocks of Tahiti with chemical analyses, laying particular stress on the syenitic varieties and on the haüynophyres, with certain limburgitic lavas, but noting the fact that the preponderant rocks of the islands are basalts rich in olivine. From the emphasis laid upon the alkalic rocks, one gets the impression that they are more abundant than is actually the case. However, their theoretical importance has not been exaggerated. More recently Marshall has analysed and described phonolitic rocks from the Leeward Islands and from Raratonga, Cooks Islands, and has analyzed several rocks from Tahiti. So there are already a number of chemical analyses of igneous rocks from the islands of this part of the Pacific Ocean.

In order to extend the investigation somewhat further, and to include the more common varieties of basalt so as to give a clearer idea of the prevailing rocks of the islands, chemical analyses have been made of rocks from different islands of the Georgian and Society groups. These have been placed in sequence in one table for comparison with one another, and to show the resemblances among the various lavas of these islands. The analyses have been obtained in part with the aid of grants 192 and 203, from the Bache Fund of the Academy. That is, those by Professor Foote and by Dr. Washington. The microscopical study has also been carried on with the aid of these grants. As the specimens collected represent over 550 rocks from seven volcanic islands, it is only possible in this preliminary statement to notice particularly the 30 specimens whose analyses are published for the first time in the accompanying table, with some observations concerning their relations to the rocks with which they are associated.

The rocks of Tahiti are almost wholly basalts rich in olivine and augite,

with few or no phenocrysts of feldspar. They differ from one another somewhat in the size and abundance of the phenocrysts of olivine and augite. At one extreme are basalts with abundant phenocrysts; at the other are basalts without any, but with ill-defined spots which are lighter colored than the body of the rock. Such basalts form large flows often in superposition, as at Point Tapahi on the north coast where a strongly porphyritic basalt forms the lower layer or flow, at the water's edge, and a non-porphyritic spotted basalt forms the upper flow. The upper rock has been analyzed, no. 19 in the table, and proves to be a limburgose, bordering on camptonose, with 8.5% of normative nephelite. The light-colored spots in the rock are probably due to areas of altered nephelite, or to analcite. The rock is aphanitic, and under the microscope is seen to be holocrystalline; composed of augite, magnetite, ilmenite, and olivine in a matrix of plagioclase with nephelite or analcite. Similar basalt forms a massive flow and has been quarried near Papeete. A strongly porphyritic basalt rich in olivine, like the rock at Point Tapahi, is in place on the road farther west. Its analysis, no. 27, shows it to be uvaldose, a highly mafic rock without normative nephelite. It is holocrystalline; the groundmass crowded with augite, olivine and magnetite, with quite subordinate amount of plagioclase feldspar. It is in fact limburgite. These two varieties of basalt are common throughout the islands visited, a very similar rock, no. 28, having been analyzed from the west coast of Raiatea. It is, however, somewhat more coarsely crystalline, the individual crystals being distinctly visible microscopically. Some of the plagioclase feldspars have outer zones of alkalic feldspar, probably soda-orthoclase.

A limburgitic basalt which appears to be a large massive body, exposed in Fautaua Valley on the trail above the waterfall, is a gray rock with small miarolitic cavities. It is holocrystalline and consists of abundant subhedral, violet-tinted augites, of variable sizes, with much colorless olivine, subhedral magnetite, in part dendritic, and areas of poikilitic plagioclase, with patches where the matrix is alkalic feldspar and analcite. The chemical analysis is no. 26 and the norm is relatively high in alkalic feldspar, low in anorthite, with 7% of normative nephelite. There is 5% of apatite which appears as thin acicular prisms. A corresponding amount of apatite occurs in a theralite from Taiarapu, analysis 22. Another basalt from Fautaua Valley is found in boulders in the stream near the ridge above the falls. Its chemical composition, no. 25, is similar to the rock just described, no. 26, but it appears somewhat differently under the microscope. It consists chiefly of violet-tinted augite, with abundant colorless olivine, and magnetite, and clusters of rods of ilmenite, with minute needles of augite. Between these is a small amount of colorless matrix which is in part plagioclase feldspar. The norm shows a small amount of anorthite, 19% of feldspathoids, and no alkalic feldspar. There is about 2% of calcium orthosilicate which does not appear as melilite in the mode, and is probably incorporated in the mafic minerals. This is also a limburgite.

A basalt still richer in olivine, of the utmost freshness occurs on the east side of Raiatea, its analysis, no. 24, shows 23.97% of magnesia, or nearly 45% of normative olivine. It is a most beautiful chrysophyre, or limburgite, with a holocrystalline groundmass crowded with microscopic augites, olivines, magnetite and subordinate plagioclase. On the Island of Moorea a limburgite with similar chemical composition, no. 23, was found in large blocks, but not in place. It is more coarsely crystallized and resembles a peridotite megascopically. It is perfectly fresh and has a scant matrix of microscopic plagioclase. The norms of these highly olivinitic basalts do not contain normative nephelite, but contain normative hypersthene. The silica is comparatively high for the amount of alumina, which is low; the magnesia being abnormally high.

In the central core of the dissected volcano of Tahiti, and in that of Taiarapu, there are coarse-grained theralites which are chemically similar to the non-porphyritic basalt forming the upper flow at Point Tapahi, Tahiti. Their analyses are nos. 20, 21, and 22. They are limburgose and limburgose-etindose, and are characterized by notable amounts of normative nephelite, which is also modal. In no. 22 there is also normative leucite, which, however, does not appear in the mode, which contains considerable biotite. The theralite from Vaitipihia, Tautira Valley, Taiarapu, no. 20, is rich in augite, brown amphibole and biotite, with subordinate plagioclase and nephelite. That from Maroto River, in the Papenoo Valley, Tahiti, no. 21, is very much like no. 20, but has less amphibole and a slightly different texture. The other theralite from Vaitipihia, no. 22, contains large brown amphiboles, surrounded by brown biotite, with little augite, and much apatite. The chemical compositions of coarse-grained rocks of unusual mineral composition from the core of Taiarapu are given in nos. 29 and 30. The first is a narrow vein of pyroxenic rock traversing basalt. It consists almost wholly of slender dendritic crystals of augite in a microscopically fine-grained matrix. The norm has 45% of diopside, 5% of olivine, 26% of anorthite and small amounts of normative nephelite and leucite. The second rock, no. 30, is a peridotite composed of augite, olivine, brown hornblende, iron ores and pyrite, with very small amounts of feldspathic minerals; the norm containing a little normative nephelite and leucite.

The analyses of other basalts from these islands are given in nos. 14 to 18 in the table. They are camptonose and camptonose-auvergnose, and are from Moorea, Huahine, Tahaa and Bora Bora. The basalt from Tahaa, no. 14, is rather coarse-grained and forms a dike near the coast on Rei Point. It is the rock used for ballast by small boats in this region, and may be found in the ports on various islands, and is probably the rock called granite by early explorers. It is a dolerite and looks like a fine-grained gabbro. It is rich in olivine and its norm contains a small amount of nephelite. The basalt from Bora Bora, no. 15, is porphyritic, very rich in olivine, and has nearly the same chemical composition as no. 14. The columnar basalt from Moorea,

no. 17, and the basalt from Huahine, no. 16, are very similar chemically, while the basalt from the base of Mauratapu on Huahine, no. 18, is lower in magnesia and higher in lime and alumina. These basalts do not contain normative nephelite, and differ from one another somewhat in texture.

From the foregoing it is seen that the basaltic rocks of this region, and their coarsely crystallized phases, which occur in the cores of the volcanoes of Tahiti and Taiarapu, are normatively nephelite-bearing, except some of the highly olivinitic varieties, and some others. Nephelite is visibly present in the modes of the coarsely crystallized rocks, and is possibly present in microscopic crystals in many of the fine-grained and aphanitic basalts, though it is probable that it is represented by analcite in some instances, either as a primary mineral, or as a product of alteration.

The trachytic and phonolitic lavas, which are known to occur at five of the volcanic islands visited, are very similar to one another chemically, as is shown by analyses 1 to 8. The rocks from Nutae, no. 3, and Point Riri, no. 6 on Taiarapu, are light gray and but slightly porphyritic, with fissile parting and satin lustre. The first occurs as boulders on the beach associated with haüynophyre. The second is in place, and is exposed in large blocks. Each contains a small amount of normative nephelite, and a little that can be identified as modal nephelite, so that the rocks are properly nephelite-bearing trachytes, rather than phonolites. They have a microtrachytic texture, the first one containing small scattered phenocrysts of alkalic feldspar. Similar rocks occur on Huahine, nos. 1 and 5. They are darker colored and more fissile. Microscopically they appear to contain abundant minute crystals of nephelite, and to be characteristic phonolites. However, most of the rectangular crystals are alkalic feldspars and not nephelite, as their index of refraction shows. These rocks also are nephelite-bearing trachytes and not properly phonolites. The same is true of similar massive rocks from Raiatea, the fissile mass forming the top of Mount Tapioi, no. 4, and the rock of the sugar-loaf dome on the east side of the island, no. 2. These rocks are nephelite-bearing trachytes with small amounts of nephelite. The rock from the top of Mount Tapioi contains minute crystals of what appear to be sodalite scattered through the feldspars. Similar nephelite-bearing trachytes with less nephelite form large bodies of rock on Moorea, the analysis of one of them being given in no. 8.

Some varieties of these trachytic rocks, occurring on Taiarapu, contain haüynite in small crystals, and 12% of normative nephelite and are properly phonolites. Analysis 7 is from such a rock. One variety, no. 11, from the beach at Tautira consists of alkalic feldspar and andesine, with some nephelite and sodalite, and contains abundant small phenocrysts of brown hornblende, with much titanite and few augites and micas. Chemically it is very similar to a tephritic trachyte from Bauza, Columbreta, described by Becke. Its symbol in the Quantitative System of Classification shows that it is transitional. In the qualitative system it corresponds to a nephelite-latite, or

TABLE OF CHEMICAL ANALYSES AND NORMS OF LAVAS FROM SOUTH PACIFIC ISLANDS

	1	2	3	4	5	6	7	8	9	10
SiO_2	61.98	62.20	61.07	62.44	61.90	60.48	58.84	57.61	56.33	56.68
Al_2O_3	18.72	17.85	17.77	18.87	18.37	19.35	20.30	16.47	18.44	18.73
Fe_2O_3	2.34	2.31	2.18	1.87	2.46	2.34	2.74	2.84	5.89	4.34
FeO	1.17	0.95	1.49	0.87	0.66	1.19	0.64	4.72	2.60	0.94
MgO	0.39	0.83	0.88	0.62	0.46	0.75	0.60	0.86	1.04	1.97
CaO	1.09	1.33	1.30	1.35	0.58	1.68	1.66	2.61	2.70	3.60
Na_2O	7.16	6.74	6.80	7.29	7.95	6.50	7.48	5.06	4.34	5.64
K_2O	5.66	5.80	5.57	5.66	5.36	5.90	5.72	5.97	4.82	3.85
H_2O+	1.05	0.95	1.71	0.32	1.52	0.87	0.68	1.43	1.85	1.71
H_2O-	0.42	0.36	0.11	0.17	0.61	0.25	0.31	0.35	0.52	0.80
TiO_2	0.26	0.57	0.94	0.62	0.20	0.72	0.72	0.51	0.88	0.91
ZrO_2			0.12					0.00		
CO_2			none					0.03		
P_2O_5	0.03	0.14	tr.	0.09	0.01	0.16	0.13	0.42	0.61	0.74
Cl								0.08		
F								n. f.		
S			none					0.04		
Cr_2O_3	tr.	tr.		tr.	tr.	tr.	0.02	0.00	0.00	tr.
MnO	0.30	0.24	0.05	0.21	0.26	0.14	0.12	1.39	0.11	0.33
BaO			none			0.14	0.07	1.02		
SrO							0.00	0.01		
	100.57	100.27	99.99	100.38	100.34	100.47	100.03	100.42	100.13	100.24

Norms

	1	2	3	4	5	6	7	8	9	10
Q									7.02	0.60
or	33.92	34.47	33.36	33.92	31.69	35.03	33.92	35.58	28.36	22.80
ab	51.87	52.92	50.83	51.87	52.40	46.63	41.39	40.35	36.68	47.68
an	1.67	1.11	1.39	1.67		6.12	4.73	4.45	9.73	13.07
ne	4.83	2.27	3.69	5.40	6.53	4.54	11.93	1.42		
C									2.45	0.41
Z		0.18								
ac					2.31					
di	2.65	3.67	3.89	3.34	2.48	1.08	2.16	4.80		
wo	0.23									
hy									2.60	4.90
ol		0.28	0.28			0.98	0.35	5.81		
mt	3.25	2.32	2.09	1.62	2.31	2.32	0.23	4.18	6.03	1.62
il	0.61	1.06	1.82	1.22	0.46	1.37	1.37	0.91	1.67	1.67
hm		0.64	0.80	0.80	0.16	0.64	2.56		1.76	3.20
ap		0.34		0.34		0.34	0.34	1.01	1.34	1.68
etc	1.50	1.31	1.87	0.49	2.14	1.26	1.08	1.96	2.37	2.51
	100.53	100.39	100.20	100.67	100.49	100.31	100.06	100.47	100.01	100.14

1. I. 5.1. (3)4. phlegrose-nordmarkose, nephelite-trachyte, road S. of Mt. Paeo, Huahine.
2. I′. 5.1. (3)4. phlegrose-nordmarkose, nephelite-trachyte, E. base of Sugarloaf peak, Raiatea.
3. I′. 5.1. (3)4. phlegrose-nordmarkose, nephelite-trachyte, Nutae, Taiarapu, Tahiti.
4. I′. 5.1. ′4. nordmarkose, nephelite-trachyte, Mount Tapioi, Raiatea.
5. I′. 5.1. ′4. nordmarkose, nephelite-trachyte, S. W. base of Mauratapu, Huahine.
6. I′. 5.1(2). 3–4. phlegrose-nordmarkose, nephelite-trachyte, Point Riri, Taiarapu, Tahiti.
7. I′. (5)6.1′. ′4. nordmarkose-miaskose, phonolite, Vaitia, Tautira valley, Taiarapu.
8. ′II. 5.1(2). 3. monzonose-ilmenose, nephelite-trachyte, Papetoai valley, Moorea.
9. (I)II. ′5.2. 3′. pulaskose-monzonase, latite, Road, 1 km. E. of Papetoai, Moorea.
10. (I)II. 5.2. 4. larvikose-akerose, kohalaite, Second spur W. of Mt. Tapioi, Raiatea.

Nos. 1, 2, 4, 5, 6, 7, 9, 10 by H. W. Foote; No. 3 by H. S. Washington; No. 8 by E. W. Morley.

TABLE OF CHEMICAL ANALYSES AND NORMS OF LAVA FROM SOUTH PACIFIC ISLANDS

	11	12	13	14	15	16	17	18	19	20
SiO_2	52.11	50.11	50.73	47.60	46.55	46.96	46.01	47.55	44.74	42.46
Al_2O_3	20.04	18.91	17.22	13.35	10.75	11.00	11.49	14.53	16.74	13.85
Fe_2O_3	3.27	4.55	3.62	2.83	2.66	2.22	2.27	2.23	3.70	5.21
FeO	2.15	2.51	3.74	8.02	9.49	9.42	10.17	7.53	8.53	7.58
MgO	1.50	2.49	2.72	10.86	13.39	14.21	12.72	7.01	4.80	7.76
CaO	3.90	4.70	5.66	9.47	8.72	9.46	9.50	11.13	9.88	11.28
Na_2O	5.72	7.47	7.92	3.00	2.76	1.64	1.82	2.14	4.42	3.67
K_2O	5.30	4.29	3.89	1.82	1.56	1.40	1.38	1.84	1.14	2.34
H_2O+	2.84	0.69	0.36	0.43	0.87	0.61	1.10	1.68	1.12	0.65
H_2O-	0.30	0.78	0.12	0.17	0.51	0.05	0.33	0.57	0.33	0.07
TiO_2	1.90	1.97	1.91	2.65	2.54	2.77	2.90	3.24	3.68	3.64
ZrO_2		0.01	0.00							
CO_2		0.02	0.16							
P_2O_5	0.40	0.55	0.76	0.33	0.36	0.38	0.36	0.49	0.70	0.90
Cl		0.12	0.28							
F		0.13	0.14							
S		0.23	0.29							
Cr_2O_3	0.00	0.01	0.00	0.06	0.09	0.08	0.11	0.01	tr.	0.05
MnO	0.14	0.65	0.35	0.13	0.16	0.16	0.18	0.13	0.19	0.19
BaO		0.08	0.18							
SrO		0.10	0.22							
	99.57	100.37	100.27	100.27	100.41	100.36	100.34	100.08	99.97	99.65

Norms

	11	12	13	14	15	16	17	18	19	20
or	31.14	25.58	22.80	10.56	9.45	8.34	8.34	10.56	6.67	13.90
ab	28.30	22.01	24.10	18.86	17.82	13.62	15.20	17.82	21.48	3.67
an	13.34	5.28	0.28	17.79	12.23	18.63	19.18	24.74	22.52	14.46
ne	10.79	22.15	23.00	3.41	3.12				8.52	14.77
di	2.59	11.66	17.17	21.75	22.49	20.41	19.65	21.69	17.83	28.66
wo			0.58							
hy						9.74	5.78	8.14		
ol	1.82	0.56		17.72	24.27	19.35	20.88	4.16	7.41	7.07
mt	1.86	4.41	5.34	4.41	4.18	3.48	3.25	3.25	5.34	7.66
il	3.65	3.80	3.65	5.17	4.86	5.32	5.47	6.08	6.99	6.84
hm	2.08	1.60								
ap	1.01	1.34	2.02	0.67	1.01	1.01	1.34	1.34	1.68	2.02
etc	3.14	2.07	1.35	0.60	1.38	0.66	1.54	2.26	1.45	0.77
	99.72	100.46	100.29	100.94	100.81	100.56	100.63	100.04	99.89	99.82

11. (I)II. (5)6. 2. 3(4). essexose-borolanose, tautirite Beach, Tautira, Taiarapu, H. W. Foote.
12. II. 6. 1(2) 4. essexose-lardalose, haüynophyre, Faurahi valley, Mataia, Tahiti, E. W. Morley.
13. II. 6′. 1. 4. lardalose, haüpnophyre, Ururoa valley, Tahiti, E. W. Morley.
14. III. 5′. 3. 4. camptonose, dolerite, Dike, Rei Point, Tahaa, H. W. Foote.
15. III′, 5′. ′3. 4. camptonose, basalt, Central mountain, Bora Bora, H. W. Foote.
16. III′. 5. 3(4). (3)4. kentallenose-camptonose, basalt, South of Fare, Huahine, H. W. Foote.
17. III′. 5, 3(4). ′4. auvergnose-camptonose, basalt, Mountain between bays, Moorea, H. W. Foote.
18. III. 5. (3)4. (3)4. camptonose-auvergnose, basalt, S. W. base of Mauratapu, Huahine, H. W. Foote.
19. (II)III. (5)6. 3. 4(5). camptonose-limburgose, basalt, Upper flow, Point Tapahi, Tahiti, H. W. Foote.
20. III. 6′. (2)3. 4. monchiquose-limburgose, theralite, Vaitipihia, Tautira, Taiarapu, H. W. Foote.

TABLE OF CHEMICAL ANALYSES AND NORMS OF LAVA FROM SOUTH PACIFIC ISLANDS

	21	22	23	24	25	26	27	28	29	30
SiO_2	41.70	37.59	43.86	43.45	42.78	43.05	43.46	43.29	40.28	39.68
Al_2O_3	14.55	15.18	7.42	7.21	9.26	9.21	8.69	9.10	10.68	7.35
Fe_2O_3	6.11	3.98	2.41	3.24	2.00	1.90	4.17	6.88	5.23	7.81
FeO	7.83	6.50	12.39	9.92	10.82	10.21	8.58	7.25	8.37	8.60
MgO	7.80	8.49	21.53	23.97	12.44	13.41	18.82	16.21	10.19	14.29
CaO	12.39	12.73	7.96	6.85	14.37	10.15	10.41	10.11	17.23	15.78
Na_2O	2.92	2.80	1.16	1.28	2.89	3.58	1.02	1.44	0.47	0.82
K_2O	1.80	2.38	0.66	0.68	1.24	0.73	0.54	0.88	0.41	0.47
H_2O+	0.73	2.44	0.45	0.70	0.40	0.87	1.01	1.48	2.08	0.39
H_2O-	0.01	0.13	0.18	0.36	0.05	0.90	0.42	0.54	0.39	0.01
TiO_2	3.46	5.01	2.10	2.03	2.66	3.00	2.34	2.84	4.82	4.50
ZrO_2					0.02	0.00				
CO_2					0.01	0.10				
P_2O_5	0.63	2.29	0.19	0.24	0.50	2.21	0.28	0.32	0.27	0.17
Cl					0.07	0.13				
F					0.03	0.03				
S					0.24	0.24				
Cr_2O_3	0.03	0.00	0.08	0.17	0.12	0.10	0.17	0.11	0.02	0.09
MnO	0.22	0.13	0.18	0.17	0.43	0.36	0.15	0.14	0.13	0.21
BaO					0.04	0.05				
SrO					0.06	0.00				
	100.18	99.65	100.57	100.27	100.43	100.23	100.06	100.59	100.57	100.17

Norms

	21	22	23	24	25	26	27	28	29	30
or	10.56	6.67	3.89	3.89		4.45	2.78	5.56	0.56	
ab	3.67		9.96	10.48		16.77	8.38	12.05		
an	21.41	21.68	10.29	12.23	8.62	7.23	17.79	15.57	26.13	15.29
ne	11.36	12.78			13.35	7.38			1.99	3.69
lc		6.10			5.67				1.31	2.18
di	28.84	21.01	22.67	17.82	42.61	23.42	25.29	25.59	45.32	43.46
wo										2.42
hp			2.72	1.16			6.06	4.50		
ol	6.89	8.39	41.55	44.79	17.92	25.15	26.89	19.21	5.40	12.47
cs					1.89					
mt	8.82	5.80	3.48	4.64	3.25	3.02	6.03	10.21	7.66	11.37
il	6.69	9.58	3.95	3.80	5.17	5.78	4.41	5.32	9.12	8.51
ap	1.34	5.38	0.34	0.34	1.34	5.04	0.67	0.67	0.67	0.34
etc	0.77	2.58	0.71	1.23	0.92	2.32	1.60	2.02	2.49	0.49
	100.35	99.97	99.56	100.38	100.74	100.56	99.90	100.70	100.65	100.22

21. III. 6. 3. 4. limburgose, theralite, Maroto river, Papenoo valley, Tahiti, H. W. Foote.
22. III. (6)7. 3. (3)4. limburgose-etindose, theralite, Vaitipihia, Tautira, Taiarapu, H. W. Foote.
23. IV. 1(2). 3(4). (1)2. 2. wehrlose-rossweinose, limburgite, Papetoai valley, Moorea, H. W. Foote.
24. IV. 1(2). 4. (1)2. 2. limburgite, Spur E. of Sugar-loaf peak, Raiatea, H. W. Foote.
25. IV. 1(2). 2′. 2′. 2′. montrealose-palisadose, limburgite, Fautaua valley, above falls, Tahiti, E. W. Morley.
26. (III)IV. (1)2. 2. 3. 2. 2. rossweinose-uvaldose, limburgite, Fautaua valley, trail above falls, Tahiti, E. W. Morley.
27. IV. ′2, 3, ′2. 2. uvaldose, limburgite, on road W. of Point Tapahi, Tahiti, H. W. Foote.
28. ′IV. 2. (2)3. ′2. 2. uvaldose limburgite, Spur N. of bay, W. side of Raiatea, H. W. Foote.
29. IV. 2. 1(2). 2(3). 2. brandbergose-yamaskose, augitic vein, Tautira valley, Taiarapu, H. W. Foote.
30. IV. 2. 2. 3′. 2. paolose, peridotite, Vaitipihia, Tautira valley, H. W. Foote.

tephritic trachyte, or to Lacroix's nephelite-micromonzonite. It is proposed to call this particular variety of rock, *tautirite*, from the valley in which it occurs.

On Tahiti, in the valley of Ururoa on the north coast, there is a variety of haüynophyre with microscopic haüynites, analysis, 13, which is chemically somewhat like the haüynophyres analyzed and described by Lacroix, and by Marshall. The microcrystalline groundmass consists of alkalic feldspar, augite and magnetite, with small phenocrysts of haüynite, augite and very few brown hornblendes. A similar haüynophyre occurs sparingly in the valley of Faurahi, on the southwest side of Tahiti. Its chemical analysis is no. 12. These rocks are scarce on Tahiti.

On Raiatea the heavy sheet of trachytic lava, which tops the ridge and spurs of the northern half of the island, varies somewhat in composition in different places. On the second spur west of Mount Tapioi it has numerous phenocrysts of feldspar, with fewer of mica and paramorphs of hornblende. The chemical analysis, no. 10, shows it is kohalaite, or oligoclase-trachyte. A non-porphyritic gray lava on Moorea is unusual in appearance for rocks of this region. Its chemical analysis, no. 9, shows it is latite, an aphanitic lava phase of monzonite. The corresponding monzonite occurs as a variety of the syenitic rocks in the core of the Tahitian volcano.

THE LAW CONTROLLING THE QUANTITY AND RATE OF REGENERATION

By Jacques Loeb

Rockefeller Institute for Medical Research, New York

Communicated, March 18, 1918

1. It is well known that isolated pieces of a plant or a lower animal may regenerate into a whole organism again. In order to replace the current vague speculations concerning this phenomenon by a scientific theory in the sense of the physicist, quantitative experiments are required. The writer has for the past two years made such experiments which have led to a remarkably simple law controlling the quantity of regeneration in an isolated piece of an organism. This law can be expressed as follows: The mass of tissue regenerated by an isolated piece of an organism is under equal conditions and in equal time in direct proportion to the mass of growth material contained in the sap (or blood) of the isolated piece. The experiments on which this law is based were carried out on an organism unusually favorable for investigations of this kind, namely, the plant *Bryophyllum calycinum* (known to many laymen as the Bermuda 'life plant'). When leaves of this plant are isolated from the stem they will regenerate shoots in some or many of their notches. If a piece of

stem is cut out from a plant it will form shoots from its two most apical buds. My experiments have yielded the result that the mass of shoots formed in the latter case is in direct proportion to the mass of a leaf attached to the stem; and to the mass of the isolated leaf in the former case. The data concerning regeneration in an isolated leaf have already been published[1] but will be repeated here to show the identity of the law in both cases.

2. When we cut out two sister leaves of *Bryophyllum*. *i.e.*, a pair of leaves taken from the same node of a plant, and keep them under the same condition of moisture, temperature, and light, the two sister leaves possessing equal mass will produce approximately equal masses of shoots in equal times, although the number of shoots produced by the two sister leaves may vary considerably (table 1).

TABLE 1

INFLUENCE OF MASS OF LEAVES UPON MASS OF SHOOTS REGENERATED BY LEAF

		WEIGHT OF LEAVES	NUMBER OF SHOOTS	WEIGHT OF SHOOTS	MILLIGRAMS OF SHOOTS PRODUCED PER GRAM OF LEAF
		grams		*grams*	
Experiment I. Duration, 22 days. .	8 leaves	16.430	37	1.675	102
	8 sister leaves	16.476	40	1.682	102
Experiment II. Duration, 29 days. .	9 leaves	12.022	24	1.436	119
	9 sister leaves	11.861	20	1.348	114
Experiment III. Duration, 30 days...	12 leaves, intact	18.435	25	2.884	156
	12 sister leaves, each cut into 4 pieces	17.070	50	2.747	161

When we reduce the mass of one set of the sister leaves (by cutting away parts of the leaf), while that of the other set remains intact, both sets of leaves will produce in equal time and under equal conditions shoots whose masses are approximately proportional to the masses of the two sets of leaves (table 2).

From this it follows that equal masses of leaves produce equal masses of shoots, regardless of the number of shoots. Since chemical substances (water and solutes) are the only factors among those to be considered here which can vary in direct proportion with the mass of the leaves, it follows that the quantity of shoot formation in an isolated leaf is determined by the quantity of certain material contained in the sap of the leaf. This material is probably the usual material required for growth: water, and certain solutes, sugar, amino acids, salts, etc.

3. It was necessary to test the validity of this law for the regeneration of shoots in isolated stems. The facts just mentioned suggested the method required to yield rational quantitative results. This method consisted in the measurement of the influence of the mass of a leaf attached to a piece of stem upon the quantity of shoot formation in the latter. In order to obtain strictly comparable results, it was necessary again to compare the effect of sister leaves, since sister leaves alone are sufficiently alike to guarantee comparable results. The method of procedure was as follows. Stems of *Bryophyllum* containing three nodes and one pair of leaves in the third (most basal) node were split longitudinally into two halves, each half containing one leaf. One leaf remained intact, while the sister leaf attached to the other half of the stem was reduced in size by cutting away the greater part. Six whole stems

TABLE 2

INFLUENCE OF MASS OF LEAVES UPON MASS OF SHOOTS REGENERATED BY LEAF

		WEIGHT OF LEAVES	NUMBER OF SHOOTS	WEIGHT OF SHOOTS	MILLIGRAMS OF SHOOTS PRODUCED PER GRAM OF LEAF
		grams		*grams*	
Experiment I. Duration 37 days.....	5 leaves, with center cut out	7.610	11	0.755	99
	5 sister leaves, intact	13.800	9	1.405	101
Experiment II. Duration, 25 days.....	7 leaves, with center cut out	9.899	21	1.213	122
	7 sister leaves, intact	16.935	25	1.995	118
Experiment III. Duration, 32 days.....	9 leaves, with center cut out	10.522	22	2.292	218
	9 sister leaves, intact	17.852	30	3.430	192

were used for one experiment. After splitting, the halved stems were suspended in an aquarium with the apices of the leaves just dipping in water. Each half stem formed one new shoot from the apical bud and new roots at the base, but regeneration started earlier in the half stems with a whole leaf attached than in the half stems with a leaf reduced in size. After about five weeks the regenerated shoots were cut off and weighed. It was found that *the mass of the shoots regenerated in the two sets of halved stems was in exact proportion to the mass of the leaves attached to the stems* (table 3).

A similar law seems to hold for the root formation though this will have to be determined more definitely. The same law seems also to hold for other cases of regeneration of *Bryophyllum* not discussed in this note.

We can, therefore, state that the quantity of regeneration in an isolated piece of an organism is under equal conditions and in equal time directly pro-

portional to the mass of growth material circulating in the sap (or blood) of the piece and required for the synthetical processes giving rise to the regenerated tissues and organs. If we measure the rate of regeneration by the mass of material regenerated in a given time, the law expressed for the quantity holds also for the *rate* of regeneration and in this form the law becomes a special case of the law of chemical mass action.

4. This law does not throw any light upon two other features of regeneration, namely, first, why it is that as a rule only the apical bud of an isolated piece of stem grows out and none of the buds situated more basally in the stem; and second, why it is that the same bud which grows out when the piece of stem is cut out from the whole plant does not grow out as long as the piece is part of a whole (and normal) plant. The writer published not long ago a series of experiments[2] which suggest that the growing apex (as well as the

TABLE 3

INFLUENCE OF MASS OF LEAVES UPON MASS OF SHOOTS REGENERATED BY STEM

		WEIGHT OF LEAVES	WEIGHT OF 6 REGENERATED SHOOTS ON STEM	MILLIGRAMS OF SHOOTS REGENERATED PER GRAM OF LEAF
		grams	*grams*	
Experiment I. Duration, 37 days.....	6 whole leaves	19.030	2.808	147
	6 sister leaves, reduced in size	2.853	0.443	152
Experiment II. Duration, 34 days.....	6 whole leaves	18.490	3.586	192
	6 sister leaves, reduced in size	3.503	0.668	190

leaves) of a plant continually produce and send toward the base of the plant substances which *inhibit* the growth of dormant buds. When a piece of stem is cut out from a plant these inhibitory substances contained in the stem will continue to flow toward the base, with the result that the most apical buds will be the first to become comparatively free from these inhibitory substances and hence will be the first to grow out. As soon as this happens, the growing buds will produce and send toward the base inhibitory substances, with the result that none of the more basally situated buds of the piece of stem can grow out. In the normal plant the material serviceable for growth can only be utilized by the growing region at the apex (and the base of the plant); and when a piece is cut out from the plant the same material becomes available for the growth of those buds which are the first to be freed from the inhibitory material which they contained while forming parts of the whole plant. The further qualitative as well as quantitative experiments which the writer has carried out since the publication of his preliminary note support this hypothesis.

Summary.—By measuring the influence of the mass of a leaf attached to an isolated piece of stem upon the process of regeneration in the piece, it has been possible to prove that the quantity of regeneration is in equal time and under equal conditions in direct proportion to the mass of the leaf. Since nothing except substances produced and sent out by the leaf can vary in direct proportion to its mass, it follows that the quantity of regeneration in an isolated piece of an organism is under equal conditions determined by the mass of material necessary for growth circulating in the sap (or blood) of the piece. If we measure the rate of regeneration by the mass of material regenerated in a given time, the law of regeneration becomes a special case of the law of chemical mass action. That this mass action on a bud is only possible in a piece of stem after it is isolated, the writer explains on the assumption that the apex of an intact plant sends constantly inhibitory substances into the stem preventing the buds contained in the stem from growing and consuming the material required for growth. When a piece of stem is isolated, the supply of these inhibitory substances from the growing region ceases and the most apical bud being the first to become free from the inhibitory substance will then come under the influence of the acting masses of the substances in the sap and regeneration will occur. The mystifying phenomenon of an isolated piece restoring its lost organs thus turns out to be the result of two plain chemical factors: the law of mass action and the production and giving off of inhibitory substances in the growing regions of the organism.

[1] Loeb, J., *Science, New York*, **45**, 1917, (436); *Bot. Gaz., Chicago*, **65**, 1918, (150).
[2] Loeb, J., *Science, New York*, **46**, 1917, (547).

NATIONAL RESEARCH COUNCIL

MINUTES OF EXECUTIVE BOARD OF WAR ORGANIZATION

FIRST MEETING, TUESDAY, FEBRUARY 26, 1918

The meeting convened at 9.30 a.m. in the offices of the Council, 1023 16th Street, Washington, D. C., with Mr. Hale, the Chairman of the Council, in the chair.

Present: Marston T. Bogert, John J. Carty, Whitman Cross, Gano Dunn, George E. Hale, John Johnston, Vernon L. Kellogg, Charles E. Mendenhall, Richard M. Pearce, Charles D. Walcott, Robert S. Woodward, Robert M. Yerkes, and by invitation, Henry N. Russell.

The minutes of the joint meeting of the Council of the National Academy of Sciences and the Executive Committee of the National Research Council of January 17, 1918, were presented and approved.

The Chairman of the Council reported:

1. That arrangements have been made to rent the building at 1015 16th Street N.W., at a rental of $250 per month, from March 1 to September 15, 1918, in order to accommodate the growing activities of the Council, particularly in coöperation with the U. S. Signal Corps.

2. That Mr. Johnston has accepted his election as Executive Secretary of the Council to date from February 1, 1918.

3. That Sidney W. Farnsworth of the Westinghouse Electric Company has been appointed Technical Assistant of the London Section of the Research Information Committee, and that all members of the London and Paris Sections of this Committee have sailed for their posts of duty, with the exception of Mr. Farnsworth, who will leave shortly.

4. That for personal reasons it has become necessary for Harold D. Babcock, Technical Assistant of the Washington Section of the Research Information Committee, to resign and to return to California. His resignation took effect on February 17, 1918.

5. That Graham Edgar of Throop College of Technology, has accepted appointment as Technical Assistant of the Washington Committee in Mr. Babcock's place and expects to assume his duties about March 15.

6. That Clarence H. Mackay has contributed the sum of $1000 for expenses in connection with the work of the Sub-Committee on Protective Body Armor of the Engineering Committee of the Council.

7. That the Chairman has prepared a report of the activities of the Council for the year 1917, to be incorporated in the annual report of the National Academy of Sciences, and that with this report will also appear a statement of the contributions and appropriations which have been made available for expenditure under the direction of the Council or with its coöperation.

The Chairman of the Council submitted the following report of action taken by the Executive Committee of the Executive Board of the Council under authority granted at the joint meeting of the Council of the National Academy of Sciences and the Executive Committee of the National Research Council, on January 17.

1. That the following six members at large have been appointed to membership on the Executive Board of the Council:

John J. Carty, Arthur A. Noyes, Van H. Manning, Michael I. Pupin, William H. Welch and Robert S. Woodward.

2. That it has been impossible for Major Flexner to accept the chairmanship of the Division of Medicine, Hygiene, Surgery, Anatomy, Anthropology, Physiology, Psychology and Zoology, and that Richard M. Pearce, of the University of Pennsylvania, has been appointed Chairman in his place, and that the title of the Division has been changed to read "Division of Medicine and Related Sciences."

3. That an Executive Committee of the Division of Medicine and Related Sciences has been appointed as follows:

Richard M. Pearce, Chairman, Robert M. Yerkes, Vice-Chairman, Charles B. Davenport, Simon Flexner, William H. Howell, Charles H. Mayo, William J. Mayo, F. F. Russell, Edward R. Stitt, V. C. Vaughan, and William H. Welch.

4. That an Executive Committee of the Division of Geology and Geography has been appointed as follows:

John C. Merriam, Chairman, Whitman Cross, Vice-Chairman, Frank W. DeWolf, Douglas W. Johnson, and Philip S. Smith.

5. That Vernon L. Kellogg, of Leland Stanford Junior University, has been appointed Chairman of the Division of Agriculture, Forestry, Botany, Fisheries and Zoology.

6. That Charles E. Mendenhall has been appointed Vice-Chairman of the Division of Physics, Mathematics, Astronomy and Geophysics.

7. That Henry M. Howe, Bedford Hills, New York, has accepted appointment as Chairman of the Section on Metallurgy of the Engineering Division of the Council.

The Chairman also presented the following financial statement showing expenditures on account of the work of the Council since the meeting of the Executive Committee of January 17.

Account in Riggs National Bank

Balance on hand January 17, 1918		$551.93
Total deposits January 17 to February 26		5000.00
		$5551.93
Salaries	$547.59	
Expenses and Supplies	3615.43	
Equipment	568.62	
Total expenditures	4731.64	4731.64
Balance on hand		$820.29

Upon motion Colonel Carty was nominated and elected as Chairman of the Executive Board of the Council, and thereupon occupied the chair.

The resignation of Russell H. Chittenden as Chairman of the Committee on Research in Educational Institutions was presented and accepted with regret.

After discussion the appointment of an Executive Committee of the Executive Board of the Council was reconsidered and upon motion the previous action in establishing such a Committee was rescinded. Thereupon it was

voted, upon motion of Mr. Dunn, that a small Committee with executive powers, consisting of the general officers of the Council and of the Chairmen of its Divisions, be appointed, to be known as the Interim Committee, to serve between meetings of the Executive Board for consideration of current business. It was also voted that five members of the Interim Committee shall constitute a quorum.

Mr. Dunn spoke of the desirability of maintaining reciprocal relations and associations with the Engineering Foundation, and after discussion it was

RESOLVED, that in conformity with the policy of The Engineering Foundation expressed in its resolution of September 20, 1917, addressed to the National Research Council, and subject to the approval of The Engineering Foundation, the National Research Council hereby designates Alfred D. Flinn, secretary of The Engineering Foundation, as assistant secretary of the National Research Council, without salary, for a period of one year from date, and in turn is ready reciprocally to approve the designation by The Engineering Foundation of John Johnston, secretary of the National Research Council, as an assistant secretary of The Engineering Foundation on the same terms and for the same period.

Upon suggestion of the Chairman of the Council, an Information Section of the Administrative Division was established, to include the work of the Research Information Committee and other similar activities. He read the following statement relative to the purpose and functions of the Research Information Committee.

RESEARCH INFORMATION COMMITTEE

1. By joint action the Secretaries of War and Navy, with the approval of the Council of National Defense, have authorized and approved the organization, through the National Research Council, of a Research Information Committee in Washington with Branch Committees in Paris and London, which are intended to work in close coöperation with the offices of the Military and Naval Intelligence, and whose function shall be the securing, classifying, and disseminating of scientific, technical, and industrial research information, especially relating to war problems, and the interchange of such information between the Allies in Europe and the United States.

2. In Washington the Committee consists of:

(a) A civilian member, representing the National Research Council, S. W. Stratton, Chairman.

(b) The Chief, Military Intelligence Section.

(c) The Director of Naval Intelligence.

3. The initial organization of the Committee in London is:

(a) The Scientific Attaché, representing the Research Information Committee, H. A. Bumstead, Attaché.

(b) The Military Attaché, or an officer deputed to act for him.

(c) The Naval Attaché, or an officer deputed to act for him.

4. The initial organization of the Committee in Paris is:

(a) The Scientific Attaché, representing the Research Information Committee, W. F. Durand, Attaché.

(b) The Military Attaché, or an officer deputed to act for him.

(c) The Naval Attaché, or an officer deputed to act for him.

5. The chief functions of the foreign committees thus organized are intended to be as follows:

(a) The development of contact with all important research laboratories or agencies, governmental or private; the compilation of problems and subjects under investigation; and the collection and compilation of the results obtained.

(b) The classification, organization, and preparation of such information for transmission to the Research Information Committee in Washington.

(c) The maintenance of continuous contact with the work of the offices of Military and Naval Attachés in order that all duplication of work or crossing of effort may be avoided, with the consequent waste of time and energy and the confusion resulting from crossed or duplicated effort.

(d) To serve as an immediate auxiliary to the offices of the Military and Naval Attachés in the collection, analysis, and compilation of scientific, technical, and industrial research information.

(e) To serve as an agency at the immediate service of the Commander-in-Chief of the Military or Naval Forces in Europe for the collection and analysis of scientific and technical research information, and as an auxiliary to such direct military and naval agencies as may be in use for the purpose.

(f) To serve as centers of distribution to the American expeditionary forces in France and to the American naval forces in European waters of scientific and technical research information, originating in the United States and transmitted through the Research Information Committee in Washington.

(g) To serve as centers of distribution to our Allies in Europe of scientific, technical, and industrial research information originating in the United States and transmitted through the Research Information Committee in Washington.

(h) The maintenance of the necessary contact between the offices in Paris and London in order that provision may be made for the direct and prompt interchange of important scientific and technical information.

(i) To aid research workers, or collectors of scientific, technical, and industrial information from the United States, when properly accredited from the Research Information Committee in Washington, in best achieving their several and particular purposes.

6. The headquarters of the Research Information Committee in Washington is in the offices of the National Research Council, 1023 Sixteenth Street; the Branch Committees are located at the American Embassies in London and Paris.

It was decided upon nomination of the Chairman of the Council to request the President of the National Academy of Sciences to appoint the following gentlemen, who will in future have an active part in its work, as additional members of the Council:

Henry M. Howe, Emeritus Professor of Metallurgy, Columbia University.

Vernon L. Kellogg, Professor of Entomology, Leland Stanford Jr. University.

S. L. G. Knox, President, Knox Engineering Company, San Francisco, California.

William J. Mayo, Surgeon General's Office, U. S. A.

Charles H. Mayo, Rochester, Minnesota.

Richard M. Pearce, Professor of Research Medicine, University of Pennsylvania.

Colonel F. F. Russell, Surgeon General's Office, U. S. A.

Rear Admiral Edward L. Stitt, Medical Director, Naval Medical School.

Robert S. Woodward, President, Carnegie Institution of Washington.

Mr. Johnston reported verbally with regard to plans for the section on Industrial research and Mr. Hale stated that Mr. Elihu Root has accepted appointment as a member of the Advisory Committee of this section.

The Chairman of the Council reported with regard to proposals for the organization of the Engineering Division and also stated that it has been decided to organize a Section on Design in the Science and Research Division of the Signal Corps, under the chairmanship of Mr. S. L. G. Knox.

Upon nomination of the chairman of the Division of Physics, Mathematics, Astronomy, and Geophysics, the appointment of a Camouflage Committee was approved with membership as follows:

M. Luckiesh, Chairman, Bassett Jones, Lloyd A. Jones, G. H. Thayer.

The Chairman of the Division of Chemistry and Chemical Technology reported that Samuel Avery, Chancellor of the University of Nebraska, has come to Washington to aid in the work of the Division, to which he is devoting his entire time. He also reported on the progress of work under this Division and of the close and valuable coöperation which is being maintained with the War Industries Board and other Governmental agencies.

The Chairman of the Division of Geology and Geography explained the activities of this Division and outlined the nature of the special monograph work which has been proposed by the Army War College. After discussion it was voted that the question of allotment of a sum not to exceed $6000, to be expended for this work, be referred to the Interim Committee, with authority to act. Explanation was made that of this amount the sum of $1000 would be needed for the expenses of the Assistant to Major D. W. Johnson, who expects to go to France to obtain information for the monograph work, the remaining $5000 to be used for the expenses of assistants to be engaged upon this work in Washington.

The Chairman of the Division of Medicine and Related Sciences read a report in regard to the organization, purpose, and work of this division as follows:

Purpose.—To concentrate in Washington a comparatively small body of men representing the existing committees, and thus provide for effective coöperation in the rapid organization of medical research as an aid to the solution of urgent military problems.

Field.—Medicine, Surgery, Hygiene, Physiology, Anatomy, Psychology, Psychiatry, Physical Anthropology, and closely related subjects.

Methods.—1. To coöperate closely with the Surgeon General of the Army (through Colonel Russell) and of the Navy (through Dr. Stitt) in determining urgent problems and to enlist the aid of civilian laboratories in the solution of these problems.

2. To assist the Surgeons General of the Army and Navy in procuring trained investigators to enter the respective services as contract surgeons to undertake special field investigations during short periods of time.

3. To send, if it is considered advisable, individuals to England, France, and Italy to determine the urgent problems which should be taken up without loss of time in civilian laboratories in this country.

4. To invite, if it is considered necessary, commissions or individuals from England, France and Italy to this country to advise with the Medical Division of the National Research Council.

5. To maintain correspondence with prominent medical investigators in the American Expeditionary Forces and in civilian laboratories in France, England and Italy and thus obtain reports of the important fields of research, the character of the work in progress and the needs of the workers.

6. To establish relations with and if agreeable to them, to coöperate with research organizations abroad as (a) British Medical Research Committee, (b) the Research Society recently organized in France by medical officers of the American, French and British forces, and (c) the Committee on Medical Research of the American Red Cross in France.

7. To obtain reports of all medical research organizations in this country dealing with war problems and of individuals engaged in the investigation of war problems.

8. (a) Prepare lists of individuals and laboratories equipped and ready to undertake research at short notice.

(b) Prepare lists of individuals who will hold themselves in readiness to move from laboratory to laboratory to work for shorter or longer periods on special or emergency problems or to augment existing laboratory staffs in a group of selected laboratories.

9. To maintain a bureau for the dissemination of up-to-date bibliographies of all forms of medical research bearing on war problems.

10. To hold conferences from time to time in Washington or other central city for discussion of important research problems and methods of attack.

11. To hold military medical meetings from time to time, in the neighborhood of large cantonments, for the discussion of medical problems by military and civilian physicians.

The Chairman of this Division also outlined the character of investigations already undertaken in coöperation with the Surgeon General's office of the Army. The Chairman of the Council stated that requests had been received for information which might require an extension of the proposed activities of the Anthropology Committee, operating under the Division of Medicine and Related Sciences. Upon motion it was voted that the Interim Committee be authorized to make such additional appointments to membership in the Anthropology Committee as may be advisable in order to provide adequately for future work which may be undertaken by this Committee.

Meeting adjourned at 12 o'clock.

JOHN JOHNSTON, *Secretary.*